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THE BRITISH JOURNAL OF METALS

Vol. 63 No. 379 MAY, 1961 Monthly: Two Shillings and Sixpence


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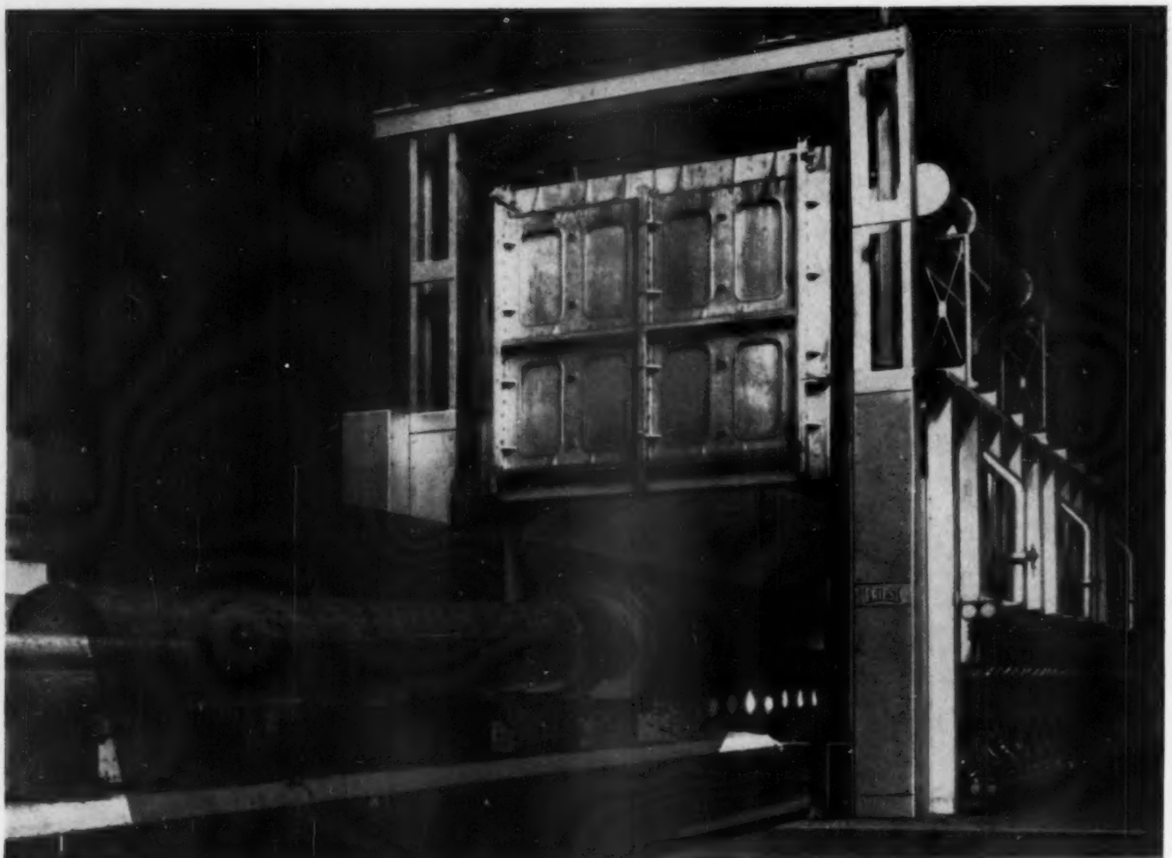

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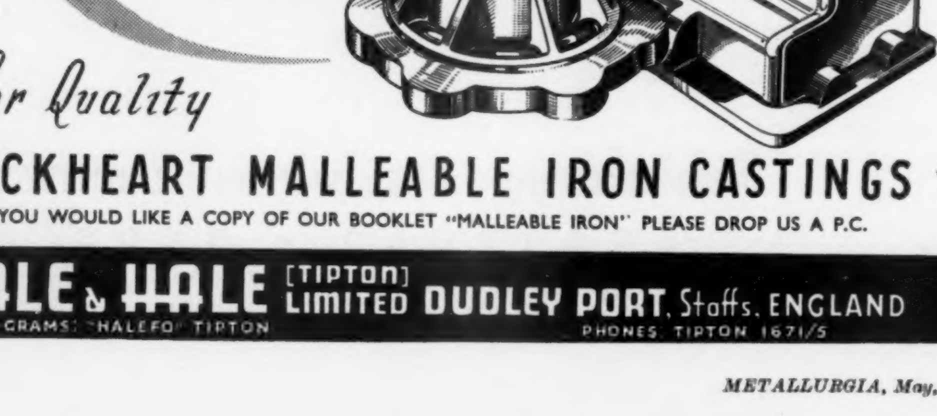

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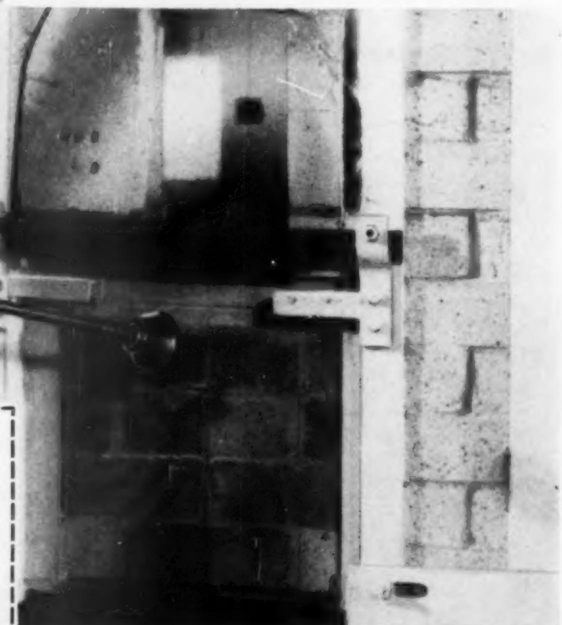

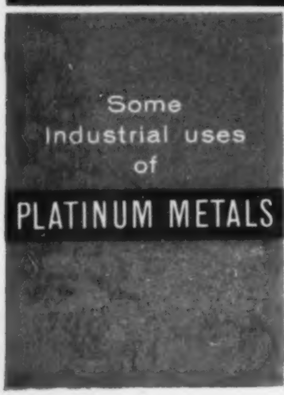

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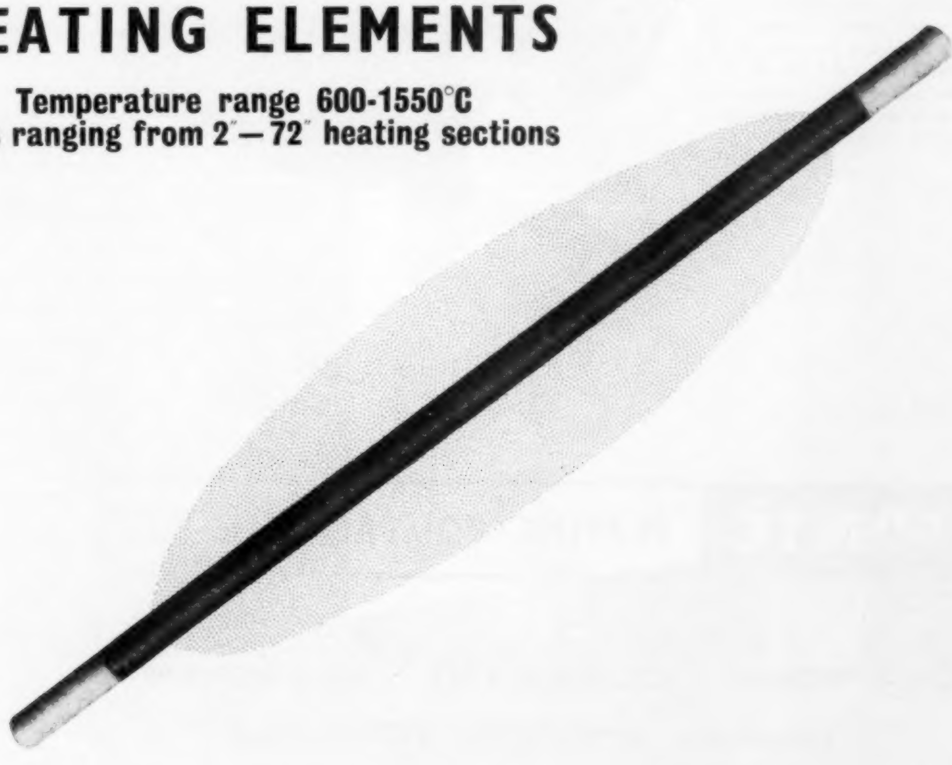

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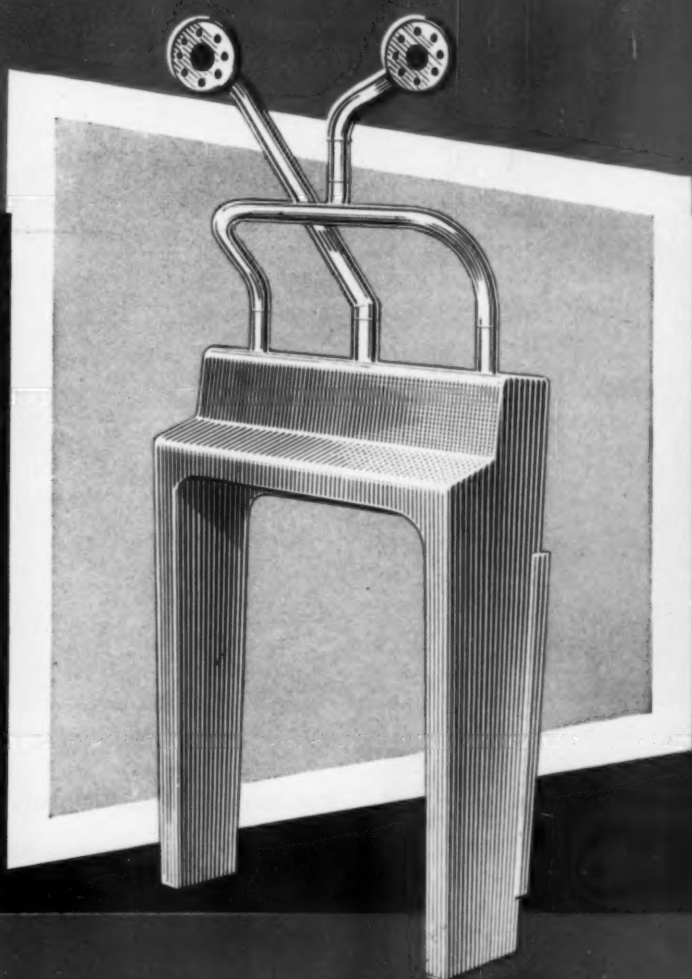

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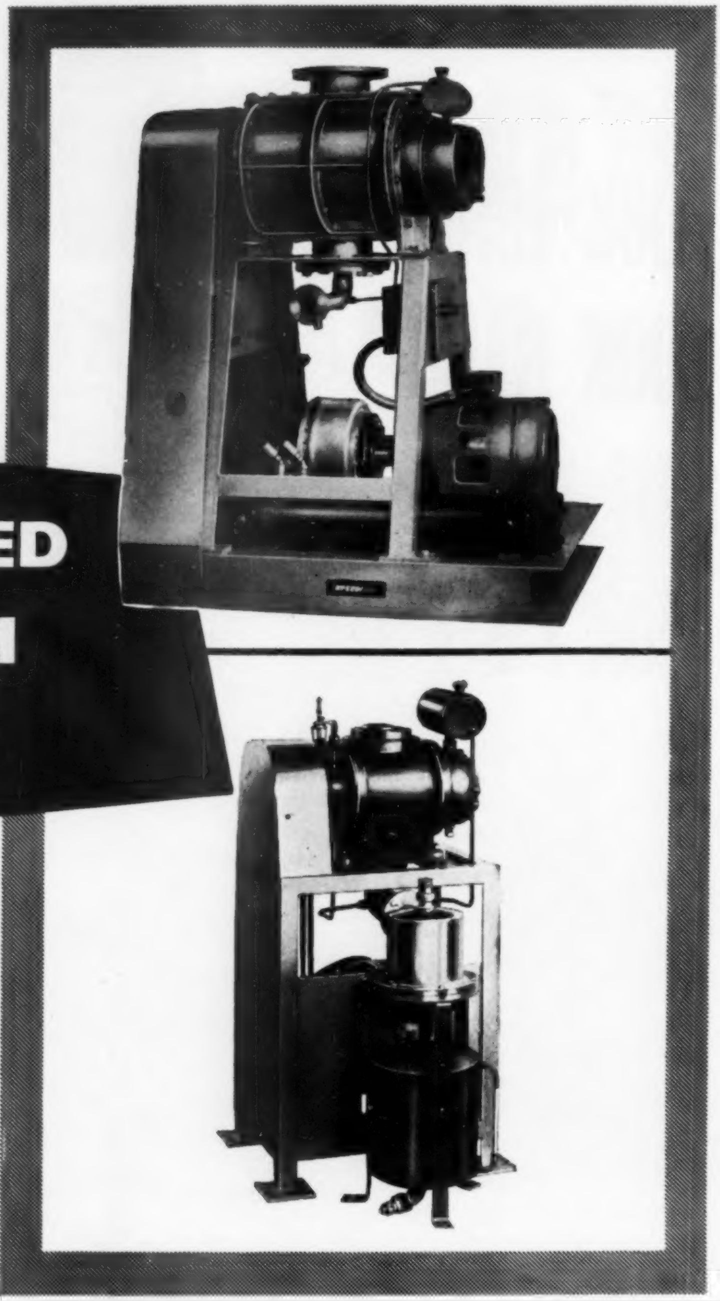

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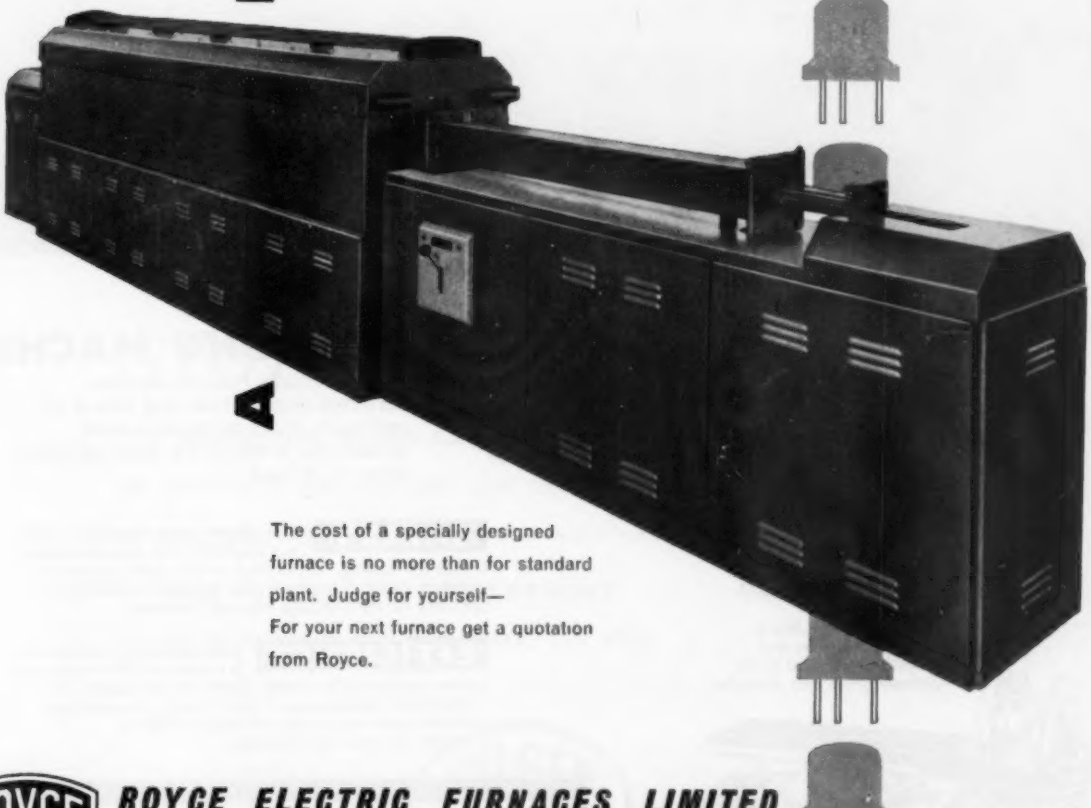

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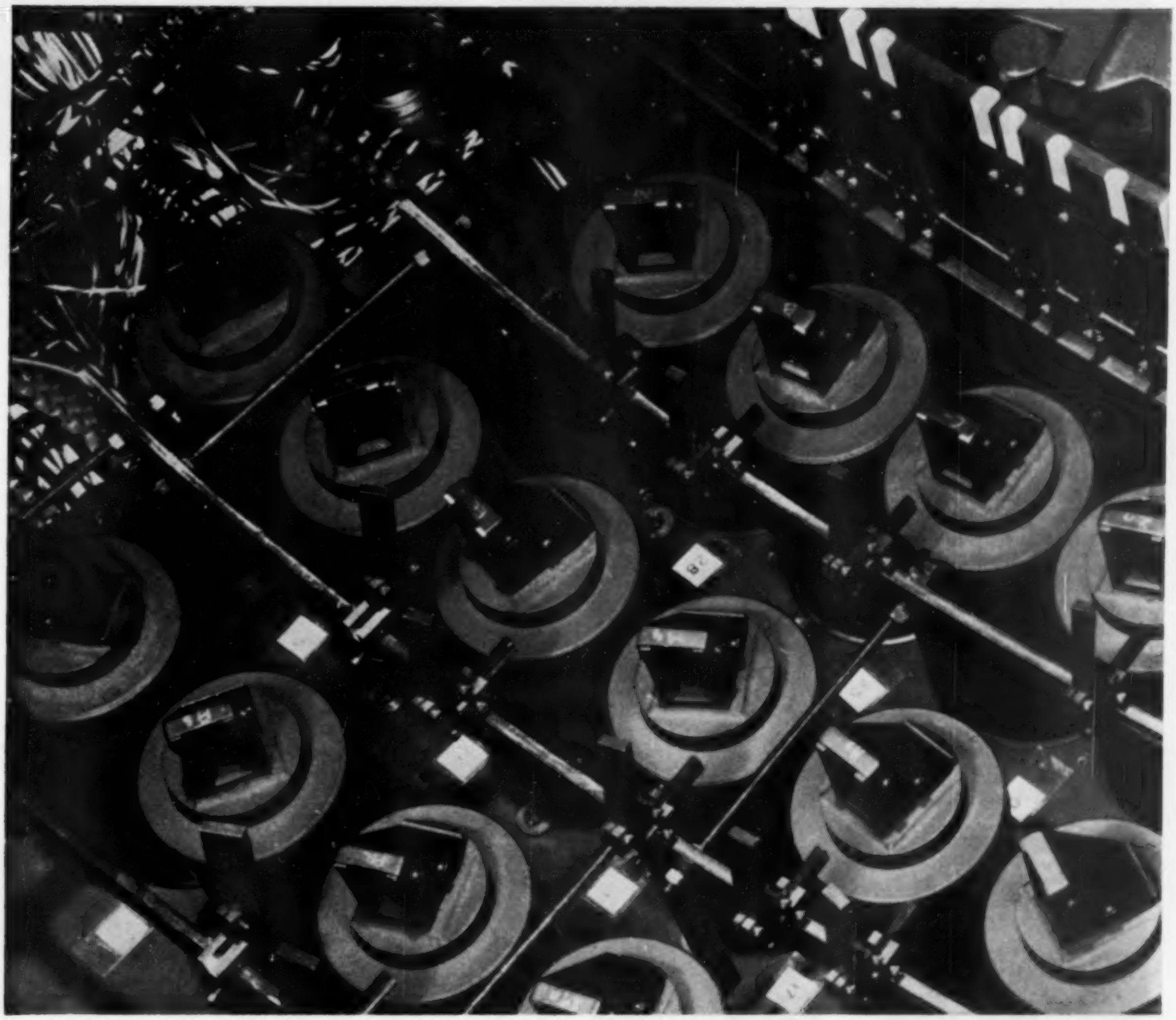

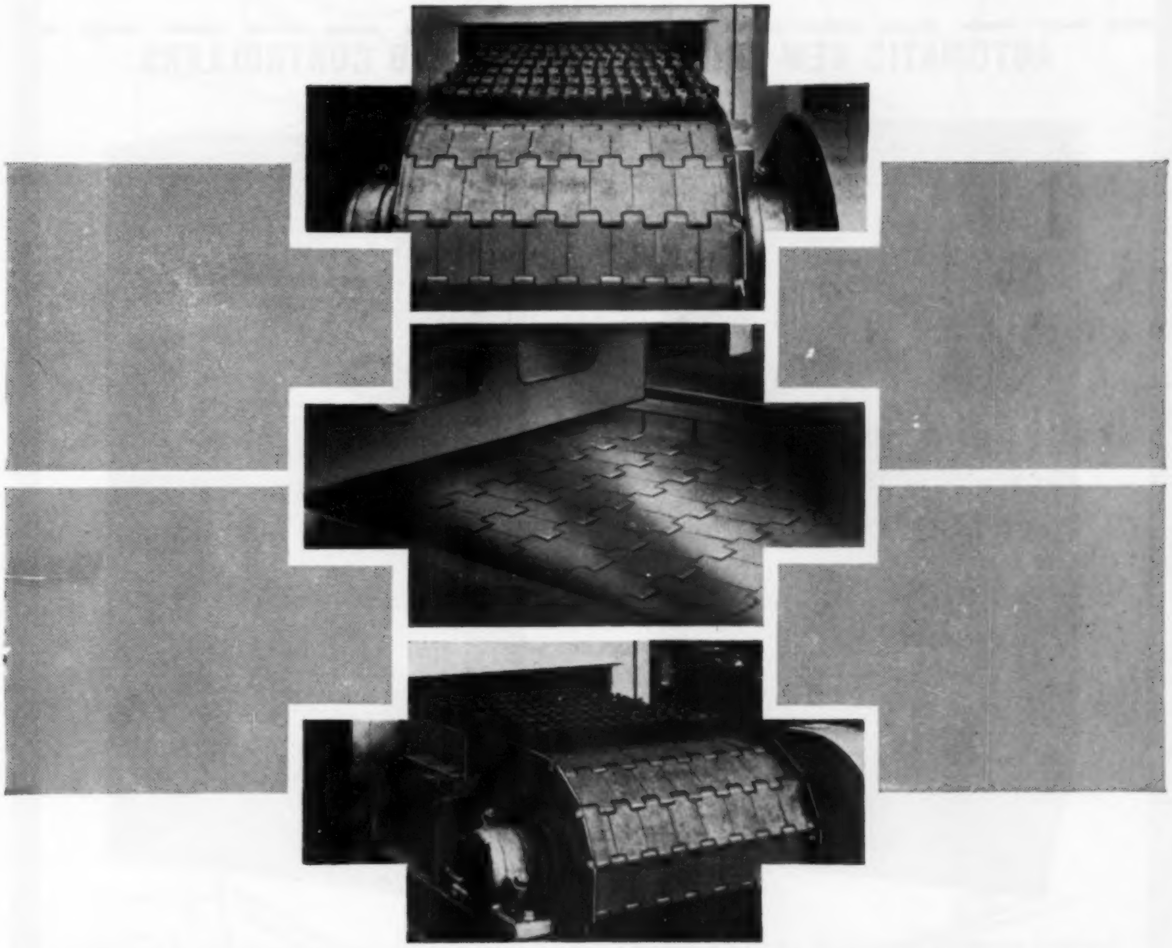

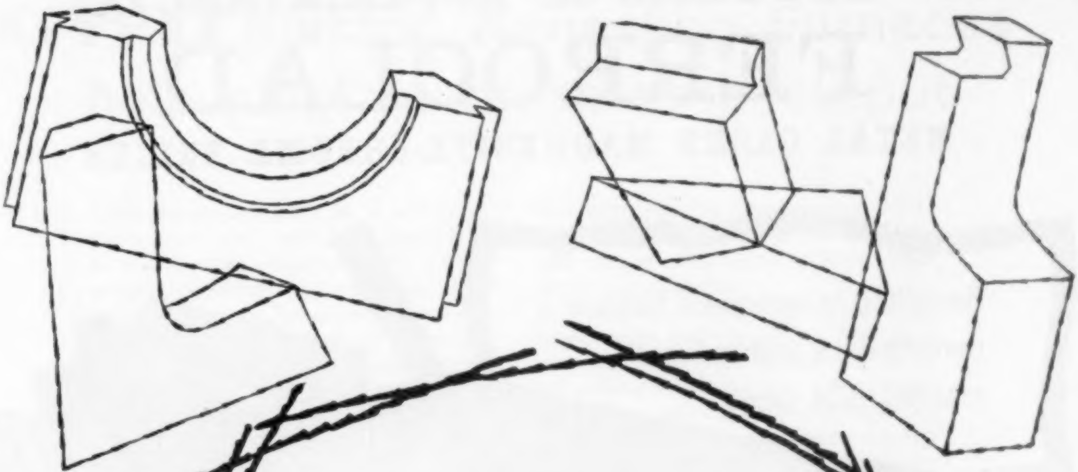

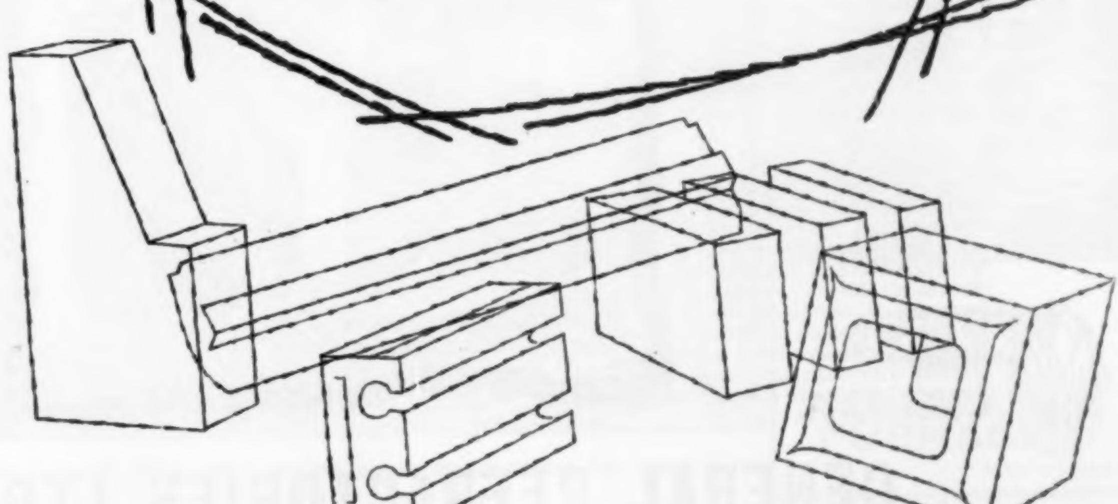

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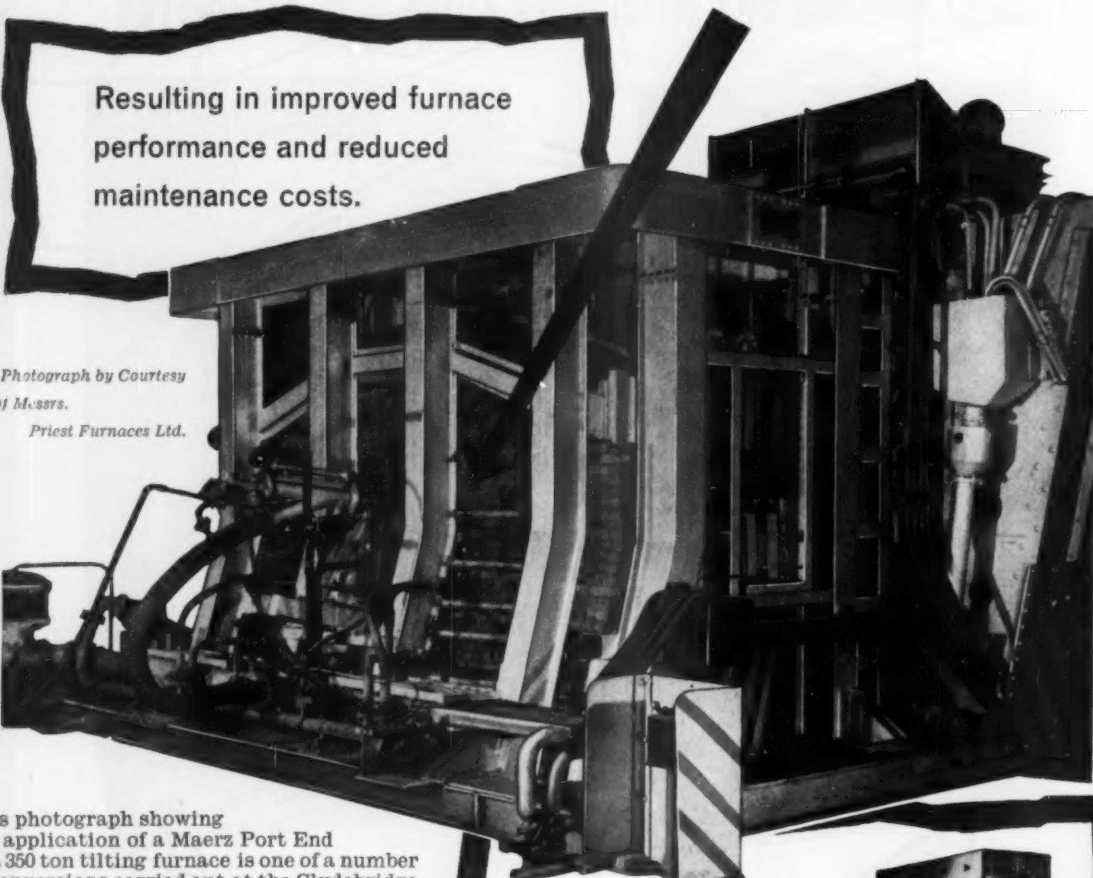
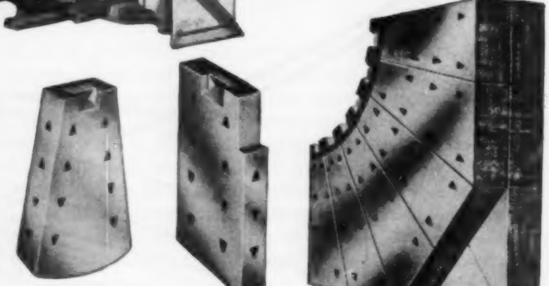


Photograph by Courtesy of Messrs. Priest Furnaces Ltd.

This photograph showing the application of a Maerz Port End to a 350 ton tilting furnace is one of a number of conversions carried out at the Clydebridge Works of Messrs. Colvilles Ltd., by Messrs. Priest Furnaces Ltd., Middlesbrough. The port end is constructed entirely of Ferroclad '70' metal-cased chemically bonded basic refractories.



Typical Ferroclad bricks used in Maerz Port End construction

G.R. Ferroclad bricks are manufactured in a range of four main qualities to suit requirements—chrome (Ferroclad 10), chrome-magnesite (Ferroclad 30), magnesite-chrome (Ferroclad 70) and magnesite (Ferroclad 100). Full particulars and recommendations for the application of Ferroclad bricks is available on request. The manufacture of Ferroclad bricks is covered by British Patents.

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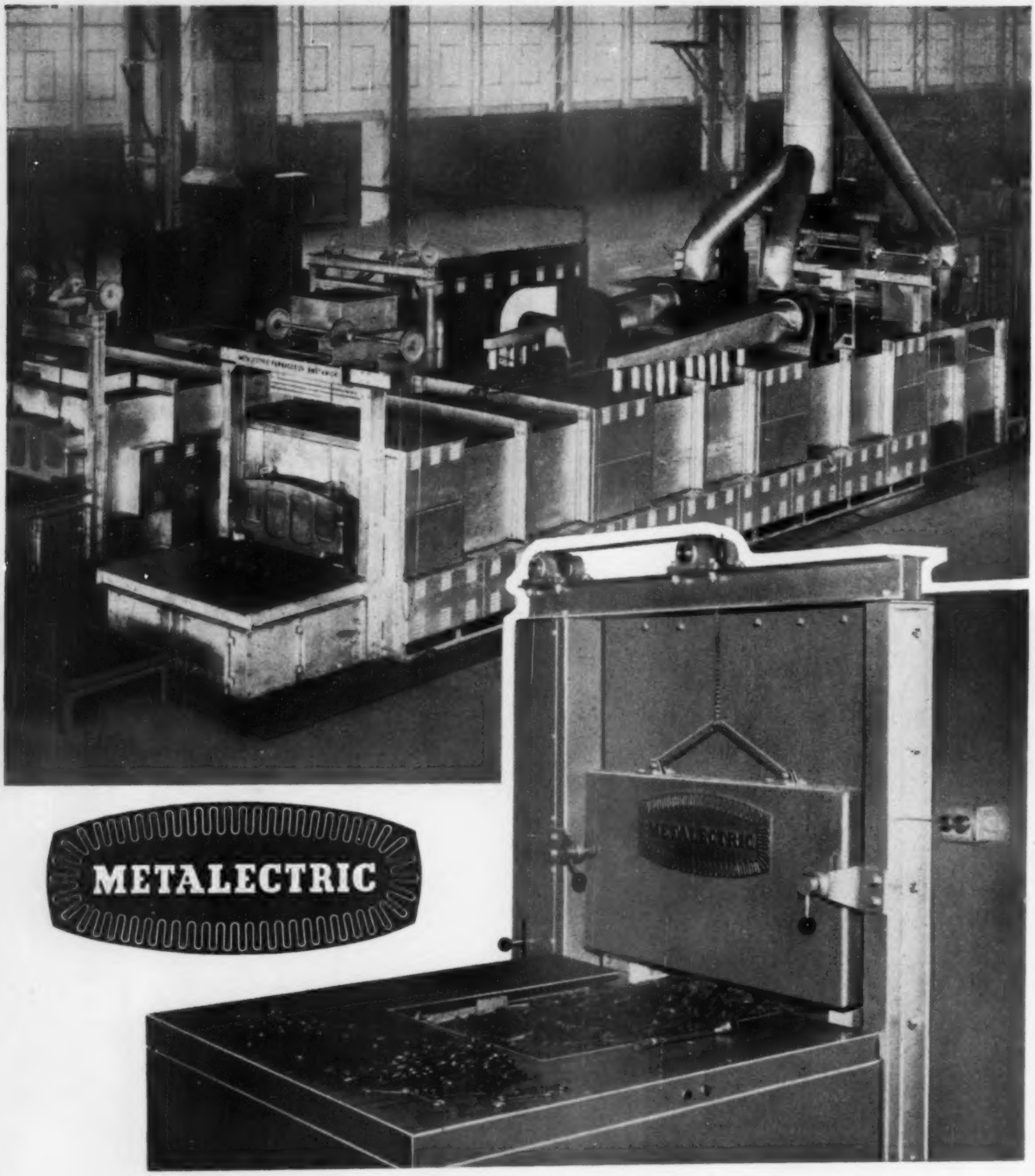

Heat treatment of forgings

The lower furnace is the latest of many Metalectric installations at Garringtons Ltd., Bromsgrove. The plant, which includes endothermic atmosphere equipment, is used for clean hardening and tempering of small tools. It supplements other installations such as the heavy duty furnaces shown in the upper photograph, which are used for the heat treatment of miscellaneous forgings.

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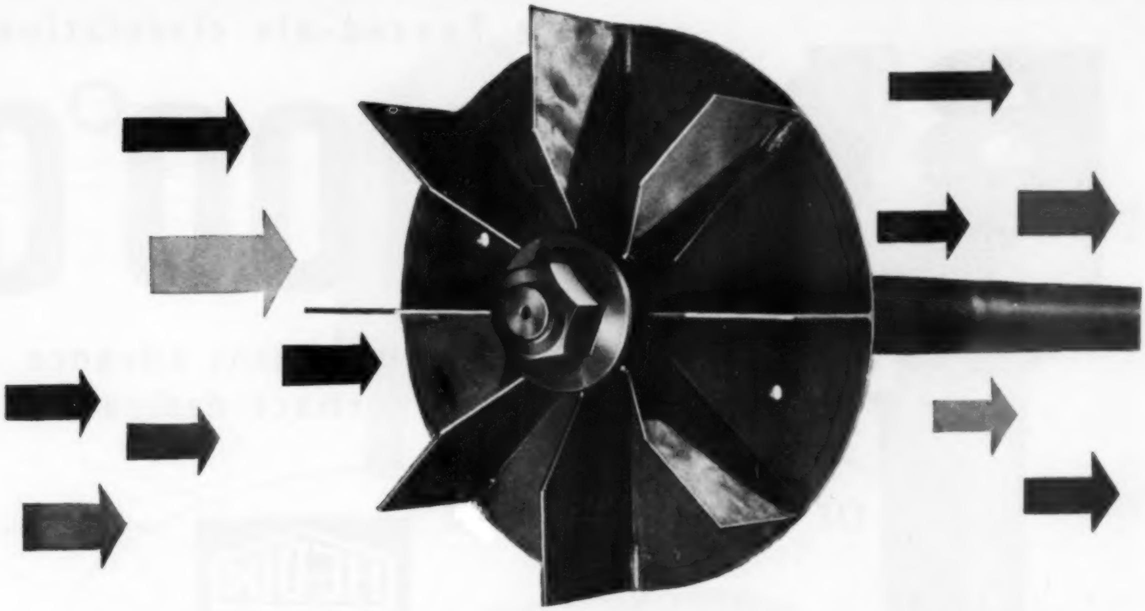

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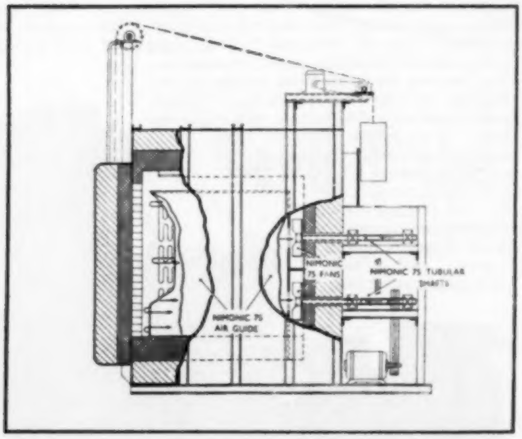

A high-temperature electric furnace of advanced design has been developed by Hedin Limited, for the heat-treatment of components during the overhaul of Rolls-Royce 'Avon' and 'Conway' turbo-jet engines.

To ensure even heat distribution within the furnace, four centrifugal fans are required to operate continuously at temperatures up to 1100°C. The nickel-chromium alloy, Nimonic 75, was selected for the construction of the fans and their drive shafts. The excellent high-temperature properties of Nimonic 75 enable it to resist oxidation and withstand the exacting centrifugal stresses at extreme heat.

TOP
In addition to the forced-circulation fans and drive shafts, Nimonic 75 is used for the air-guide furnace liner which directs circulating air over the heating elements.

INSET
Diagram shows forced-circulation system and the Nimonic 75 hollow fan-shafts cooled by compressed air.

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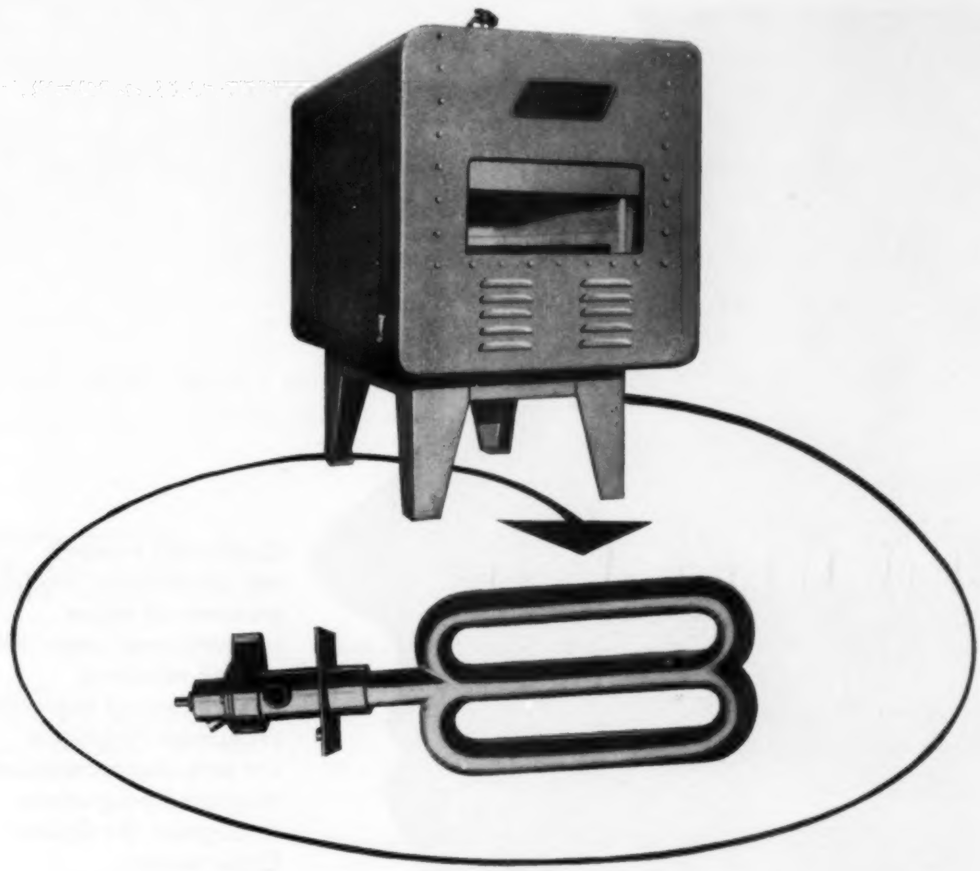

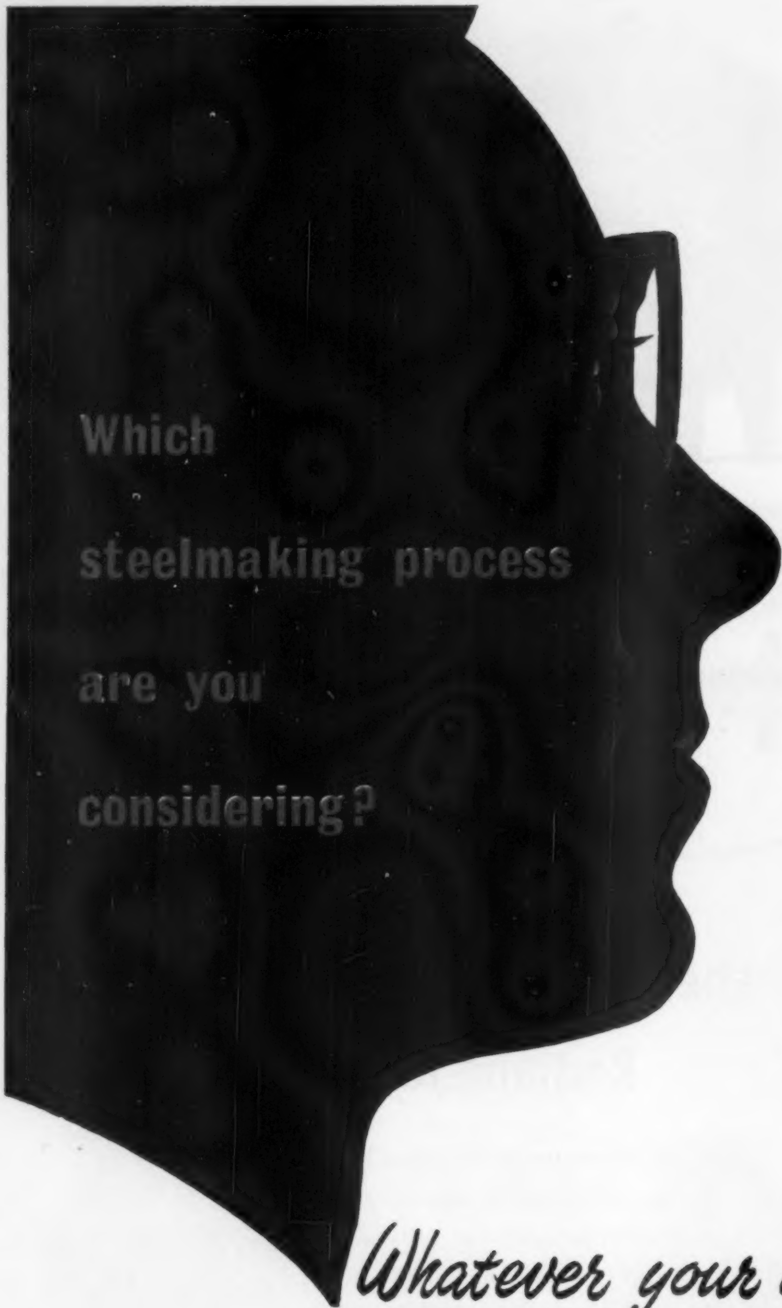
Which
steelmaking process
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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

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LABORATORY METHODS SUPPLEMENT

METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE "METALLURGICAL ENGINEER"

MAY, 1961 Vol. LXIII. No. 379

Steel in an Expanding Britain

SOME years ago, Sir Charles Goodeve, O.B.E., F.R.S., the director of the British Iron and Steel Research Association, prepared a comprehensive analysis of this country's physical and geographical advantages, coming to the conclusion that Britain was a rich and well-placed country, a land of opportunity awaiting only the full realisation of this by its inhabitants. On the occasion of his inauguration as president of The Iron and Steel Institute at the beginning of this month, Sir Charles re-examined this picture as it appears today with special reference to the steel industry.

The previous analysis was based on a consideration of Britain's inherent natural advantages—exclusive of its population. Soils and climate, mineral and energy resources, access to the sea, internal communications and geographical location—these were the chosen criteria. This time Sir Charles added a sixth—Britain's position in the Commonwealth. An abridged version of the presidential address* is presented here.

After pointing out that British soil is generally of good quality and the rainfall and sunshine sufficient to make possible a productivity per acre almost as high as anywhere in the world ; and that in mineral resources the country is far from poor, possessing some of the finest coal deposits of any country (including coking coal), a fair amount of iron ore, and a wide variety of minerals situated close together ; Sir Charles said that Britain's greatest advantage is probably that of easy access to the sea through its many ports, water transport being about one-tenth as costly as rail or road. No works in England can be built farther than 90 miles from a port through which it has access to the world's resources in raw materials ; all the deficiencies in local mineral resources can readily be made up in this way. Again, an industry in this island has, through its ports, access to the largest potential market for its goods of any manufacturing community. To these three advantages may be added easy internal communications and the central location of this country on the globe—we are within non-stop flying distance of the capitals of countries representing over 90% of the world's population.

Sir Charles continued : "This then is a picture of a comparatively rich country. It should be able to compete commercially with Russia, a country with vast mineral resources, but with these resources spread over great distances, and all of them a long distance from the sea. There are parts of Western Europe that are richer in one or two of the elements considered above but none that is richer in all five. The United States is often looked upon as the richest country in the world, but it is deficient in respect of some of these elements. Its energy and mineral resources are very great but, as in Russia, rather widely scattered. Its climate is inferior to that of the U.K. and only a proportion of its manufacturing industry has ready access to the sea. Geographically it is far from the centre of the world."

In considering the extent to which our natural advantages have been exploited, Sir Charles suggested that something has gone wrong—or stayed wrong—with our coal industry, the pithead cost being nearly six times the pre-war figure. In spite of higher labour costs in the U.S.A., it is cheaper today to bring coal from America to Scotland and parts of South Wales than to bring it from local sources, because American productivity is higher. The rise in coking coal price over the last twenty-five years has, however, been partly offset by a 45% reduction in the average coke rate in the blast furnace, and further improvement is hoped for with the development of tuyère injection of oil.

Increased efficiency in the electricity supply industry has kept prices relatively stable, and the steel industry is able to proceed with its plans for increased electric arc and oxygen steelmaking with confidence. "The background data are not available," said Sir Charles, "but I would guess that a policy of substituting electricity, gas, or oil for large coal, of closing high-cost coal-faces, of modernising coal transport, and of freeing fuel oil prices, would reduce the delivered cost of coal by over £1 per ton, and the price of steel by nearly twice this amount."

Full advantage has not been taken of industry's ready access to the ports, as the latter have lain relatively untouched for a generation : investment has passed them by. Moreover labour troubles arise with alarming regularity on grounds which to the outsider seem quite illogical. To the steel industry, however, the worst feature is that the key ports will only take small ships, with consequent higher freight charges : there is a possible saving of nearly £1 per ton on steel made from imported ore in potential port developments.

Turning to the Commonwealth, Sir Charles insisted that Britain's membership of the group is the most unique advantage this country now has. One of the main ways of maintaining the Commonwealth links of trust, based on common basic social beliefs and a common language, on mutual knowledge and respect, is through inter-migration for educational purposes or for permanent employment, and the Government's policy in encouraging this for both purposes has been very successful. It is to be regretted, however, that few of our young people study in overseas centres, and hardly any at all in Commonwealth countries. The steel industry, too, has been advancing its internal educational system, and has been extending this to include students from overseas, a large number of whom come from India.

Its preoccupation with expansion to meet home

* The full text will be published in the June issue of *The Iron and Steel Institute Journal.*

demand has prevented the steel industry from investing in the Commonwealth abroad, and although steel developments are taking or will take place in such areas as Western Canada, Pakistan and Africa, these, with few exceptions have been left to other European and American companies to exploit. Now that steel capacity is overtaking demand at home, it should be possible to repeat the excellent efforts put forth in connection with the Durgapur works in India.

There are two main approaches to investment by the steel industry in overseas countries: one from local resources of raw materials (including fuel); the other from the local market. The excessive capital costs of the coke-oven blast-furnace assembly, unless outputs of well over a thousand tons a day are envisaged, present a formidable obstacle, but it is likely that one or other of the new ironmaking processes will alter this situation in the not too distant future. As an example, Sir Charles suggested that in an area of cheap electric power and good iron ore, such as Quebec-Labrador, the production of low-carbon pure iron in the easily shippable pellet form would provide an excellent feed for electric furnaces making higher quality steel. The saving in shipping costs would go a long way to compensate for the loss of the sensible heat in liquid iron, and it is possible that the European steel industry will import metallic iron as well as ore from such regions. "But," said Sir Charles, "our industry should not only be at the receiving end, but should be actively involved in the developments themselves if we are to get the maximum advantage."

In most cases newly developing countries do not want to make steel only for prestige purposes, but to raise living standards by releasing them from the restrictions of their balance of payments. The market for British steel in such countries need not be reduced—in fact it might even be increased—by setting up a local steel mill, provided that this mill is set up in association with a British steel-maker, and that our prices are competitive.

Sir Charles expressed the view that the biggest opportunity that this country has, is to become the principal maker of capital equipment for export to the world: "We have everything in our favour, except tradition. We have low-cost steel and other necessary raw materials. We have one of the most comprehensive ranges of users of capital equipment to be found anywhere, and much of their equipment is of modern and progressive design. Through our ports and ships we have, or could have, access by cheap transport to any part of the world. The development of air freight coupled with our central position on the globe means that spares need not be carried at local works because they can be readily flown out. We have an exchange rate which gives us a wage rate one-third that of our biggest competitor, the U.S.A. We could produce a big share of the world's carpet-making machinery, bottle and can-making machinery, machine tools, instruments, etc., thousands of highly specialised types of equipment that can best only be produced centrally and incorporating the latest scientific and engineering knowledge so easily available to us in this country.

"The export of capital equipment is, of course, only part of a general national policy. Any already affluent country wishing to raise or maintain the standard of living of its people must try preferentially to export those goods which have the highest added value per man-hour of labour content, that is, of its people's work. It is surprising how frequently people wrongly shorten this criterion to goods of 'highest value.'

"In some fields of machinery, manufacturers have responded to this opportunity but on the whole we continue to lose ground, particularly to Germany. While we are increasing our machinery exports at what looks to be a substantial rate the rest of the world is increasing still faster. Much of this we can blame on certain traditions, born in the period when we had accumulated so much foreign investment we could buy much of our equipment abroad; traditions that once a man has learned one trade he must resist learning another. If we can learn to discriminate between useful traditions and restrictive ones we can grasp this opportunity."

Turning to the future of the steel industry, Sir Charles pointed out that about two-thirds of the steel output is consumed internally: "The steel content of consumer goods tends to fall and therefore the bigger opportunities for increased use of steel at home are in capital investment. Extensive as this has been in recent years, there are many fields in which much remains to be done. The exploitation of our natural advantages in internal transport is a case in point. Anyone who has studied internal transport becomes imbued with the enormous magnitude of the task in front of us and the benefits that will follow from action.

"A similarly encouraging future for the demand for steel lies with the building trade. The war made holes which are now being filled with new buildings; a situation with new, efficient, and (sometimes) beautiful buildings mixed with the old and decrepit is unstable and the pressure to replace the old will grow.

"We shall get our beautiful cities, our efficient roads, our Victoria Line, our Channel Tunnel, our economic farm produce marketing and distributing organisations, our decimal systems, as soon as the resources in manpower and materials permit. The second we now have; steel joins the other primary materials in being in good supply. We need only the manpower and the will."

On the question of manpower, immigration could help, but would not make the impact it has in Germany. More investment by British manufacturers in countries with a plentiful supply of labour—such as in parts of the Commonwealth—would enable that labour to make a bigger contribution to the solution of our problems. The main hope lies, however, in an increase in productivity.

Although each man in the steel industry makes 90 tons of steel a year, on average, as compared with 65 tons ten years ago, today's figure could be doubled with more modern equipment incorporating known technical improvements and a certain amount of rationalisation. The same sort of situation is prevalent in other industries, and large numbers of workers spend their time less productively than need be, because of a rigidity of thought and because their principal asset—their skill at a particular job—would be lost. "Much study and effort," said Sir Charles, "has been put into this problem of flexibility but without much effect; nor is there likely to be more effect until men look forward. This they will not do so long as they by habit look back for their security."

Although much lip service is paid to higher productivity we are losing ground in many industries. On the one hand the Government preaches high productivity, and on the other applies taxes in a way to discourage it.

(*continued on page* 222)

Cold Rolling Medium-Width Steel Strip

Consistent Quality is Brinsworth Aim

General view of the four-stand four-high tandem mill.

FOLLOWING satisfactory trials, production has now started at the £2 m. cold rolling mill which has been installed in a building adjacent to that housing the Brinsworth continuous medium hot strip mill at the Steel, Peech and Tozer branch of The United Steel Cos., Ltd. Although able to deal with all qualities of steel, the new mill will be primarily employed in the cold rolling of low carbon steels in all tempers from hard bright unannealed to dead soft and intermediate tempers in the annealed condition. The limits on the size of the ingoing raw material are 18 in. × 0·250 in. and 4 in. × 0·048 in., and the product thickness possible ranges from 0·010 in. to 0·160 in.

The primary aim in designing the Brinsworth cold mill and auxiliary plant has been the production of strip more consistent in quality, size and surface finish than ever before. Such a product is eminently suitable for use on automatic presses and where progressive tooling is required, and with the growing application of automation in the engineering industry, the demands on the mill are likely to become increasingly heavy.

The raw material for the new mill originates in the Brinsworth hot mill and, after pickling in the hot mill building, it is transferred to the cold mill building in coil form by way of a subterranean tunnel which terminates in a pit near the first stand of the primary cold mill. The coils, which normally weigh 25–30 cwt., are lifted by overhead crane and deposited on the feed carriage of the primary mill. Feeding of the coil to the pay-off reel is fully mechanised, the equipment opening out the end of the coil for feeding into the first stand of the mill, and traversing the coil onto the pay-off reel.

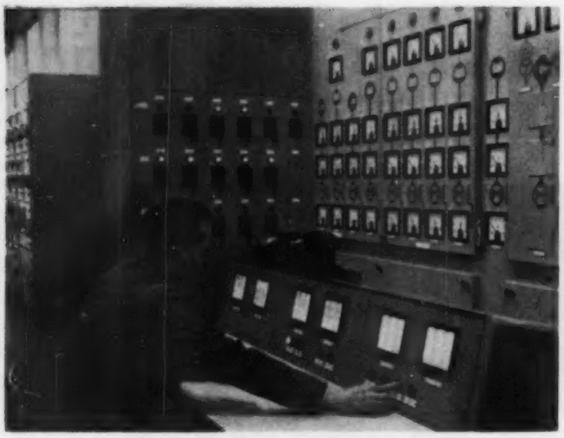
Tandem Mill Rolling

The primary operation on the pickled strip is cold rolling on a Davy-United four-stand four-high 10½ in. and 26½ in. × 22 in. tandem mill. Cold-rolled strip in medium widths is a tailor-made product—ordered in a range of tempers, gauges, widths and finishes to suit subsequent manufacturing operations—and it is not usual to roll such material on a tandem mill where tonnages of a particular class of strip are not high. The new mill has been designed to overcome the difficulties attendant on this class of work, and represents the most advanced tandem mill of this size.

Nos. 1 and 4 stands are equipped with automatic gauge control based on load cell devices, and there is inter-stand tension control between Nos. 3 and 4 stands. Variations in rolling load on stands 1 and 4, indicative of variation in gauge, operate the screw-downs to correct errors. Stand 1 serves to even out the variations in the hot rolled strip before it enters stand 2 where the major reduction takes place. Final correction to gauge takes place in stand 4, automatic tension control between stands 3 and 4 compensating for inter-stand tension variations which may result from the operation of gauge control.

On leaving stand 4 the strip passes to the coiler, from which it is mechanically unloaded by equipment similar to that used for the reverse operation at the entry end of the mill.

During the rolling operation the strip is not in contact with guides of any description, maintaining its central position in the mill by means of the inter-stand tension,



The fault finding panel in the motor room which indicates the type of fault and its location.

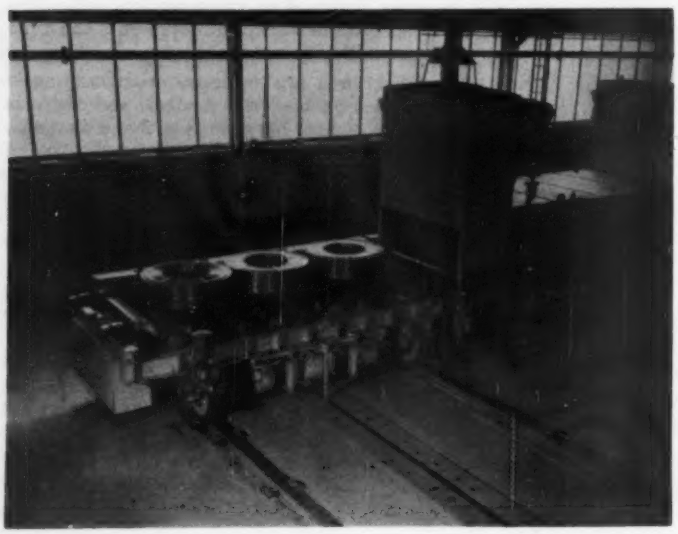
Coils of strip are placed on a tray on this tilting table, the tray being charged into one of the two annealing furnaces.

which is continuously variable. Any deviation in straightness of the strip is indicated on the panels attached to each stand, enabling the roller to make the necessary adjustments to ensure production of strip within very close limits of straightness.

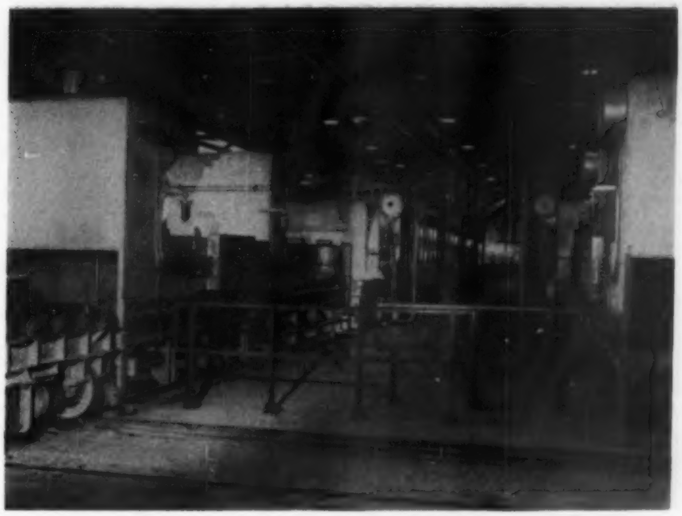
Roll gaps can be set rapidly and accurately by push-button control, and roll changes can be carried out with minimum delay—features of considerable importance in the successful use of a tandem mill for this class of work. The rolls are stripped and assembled in a fixed position in the roll shop and serviced by a mobile hydraulically-operated table, thereby expediting the operation, ensuring a more precise set-up of bearings and chocks, and eliminating any shock treatment to the rolls.

Forged alloy steel rolls are used for both work and back-up positions in all stands. The work rolls start at $10\frac{1}{2}$ in. diameter, when new, and may be used down to $9\frac{1}{2}$ in.; they weigh 9 cwt. each and have a hardness varying from 80 to 95 Shore. The 3 ton $26\frac{1}{2}$ in. diameter back-up rolls have a Shore hardness of 60 and can be used down to 24 in. diameter. Rolls are ground to all stages up to a mirror finish and, after grinding, varying degrees of matt finish can be applied by additional treatment in shot blasting equipment.

The electrical equipment for the mill, supplied mainly by The English Electric Co., Ltd., embodies many of the latest developments and techniques in rolling mill control. In order to eliminate, as far as possible, troubles associated with rotary machines, the mill motors (combined rating some 4,300 h.p.) are supplied from rectifier/inverter units which serve the dual function of powering the motors during rolling and returning power to the supply during deceleration. This type of mill drive is believed to be unique in this country. D.C. power for shop cranes, etc., is supplied by a 500 kW. germanium rectifier—a further instance of the elimination of rotary machines.



Coils of strip in position for charging into one of the annealing furnaces.



General view of the two 290 ft. long continuous annealing furnaces, showing entry lock and heating zones.

Supervision of the complex electrical equipment is carried out from a central desk in the motor room into which are built the main controls and instruments. Faults arising during rolling are immediately brought to the attention of the maintenance personnel by a warning system incorporating audible and visual elements. The latter, in the form of a flashing sign, gives the location and type of fault. As a further help in easing the work of the maintenance staff, conventional relays, with their moving parts, have been replaced by static switching, another advanced feature of the electrical equipment that is probably unique in this type of mill.

Annealing

After rolling in the tandem mill, strip may be despatched in the as-rolled bright hard condition, but the coils are usually transferred to the adjoining annealing bay. Coils from the tandem mill discharge equipment are loaded onto a tilting table which positions the coils on a tray: the tray, with its load of three coils, is then transferred to the charging end of one or other of the two annealing furnaces by means of a powered rail bogie.

The annealing plant comprises two 290 ft. long continuous furnaces, of Nassheur design and built by International Construction Co., Ltd., arranged side by side. At the entry end of each furnace there is a gas lock purging zone into which the trays are first pushed, prior to moving into the furnace proper, where a chain-driven conveyor takes over. The heating section of the furnace, which has a length of some 80 ft., is divided into five zones heated by coke oven gas from another United Steel works: zone temperatures are automatically controlled at 720°, 715°, 715°, 715° and 710° C., respectively. On leaving the heating section, the coils pass into a 160 ft. long cooling section which has a water-cooled shell. Nitrogen from Incandescent Heat Co. generating plant is used as a protective atmosphere throughout the heating and cooling zone to eliminate scaling or dis-

The two-high temper mill.

One of the two slitting machines.

coloration of the strip surface. The furnaces are designed for single stacking of coils only, resulting in greater consistency of the annealed product, and an output of 5 tons/hr. is achieved with coils down to 14 in. in width. One furnace has special settings for temperatures, speeds, soaking times and rate of cooling to enhance the ductility of deep-drawing quality steels. The complete annealing cycle takes about twenty-four hours, and on emerging through a second gas lock the coils are returned to the mill bay by a powered bogie.

Temper Rolling and Slitting

After annealing, the coils are transferred to the Farmer Norton two-high temper mill which has feeding and discharging equipment identical with that used on the tandem mill. In this mill the reduction is calculated to produce strip in the intermediate temper range from skin-passed to three-quarters hard. Coincident with the improvement in the physical properties of the strip resulting from the temper rolling process, the surface of the strip can be varied from matt finish to mirror finish, according to the surface finish of the rolls. On this mill the rolls are 19 in. initial diameter by 24 in. long, and can operate down to 17½ in. diameter.

From the temper mill, the strip is delivered to the slitting section where the coils are edge-trimmed and slit to the required width, and wound into coils of the correct inside diameter and weight. The two slitting machines are equipped with similar feeding equipment to that employed on the tandem and temper mills, but on the recoiling head the strips are kept separate by an overarm separator, and are stripped onto a receiving arm where they are finally strapped and labelled ready for despatch. To ensure accuracy of strip width, the slitting heads are assembled as a separate operation and are transferred to the slitting machine for each change of size.

A cupping test in progress in the laboratory.

Quality Control

As mentioned at the outset, the aim at Brinsworth is to produce strip of consistently high quality for automatic press work, and quality control throughout production is therefore necessarily close. Each coil is tested after each operation with the requisite testing equipment, dependent upon the physical properties and surface finish required in the end product, and for each specification a complete history is kept of the steelmaking and hot rolling practice, and of the production procedure in the cold rolling department.

A lot of money has been spent on the plant, and a lot of effort is being put into its operation to ensure that high standards of quality are consistently maintained, but if the country's industrial expansion continues, there seems little doubt that the reward will be reaped in the form of full order books in the years to come.

The directors of Edwards High Vacuum, Ltd., have announced that terms have been agreed for the acquisition of the whole of the issued capital of J. H. Holmes & Son, Ltd., a private company. Holmes carry on business as precision engineers and have been acting as a principal sub-contractor of Edwards. The acquisition is with a view to expanding this company as the specialised high precision machine division of the Edwards group of companies, covering aspects outside the present facilities of the group.

How are we to get more from our steels?

By G. O. H. Sjogren

In the course of this article the author suggests that a steel capable of giving uniform final hardness through the section of a machine part is not necessarily the most suitable material for such a part. Steels of high hardness are intrinsically stronger than those of lower hardness, and their sensitivity to stress raisers can be reduced by high surface compressive stresses, which may be developed to the depth required by differential hardening effects, depending on low hardenability, selective hardening, or a combination of both.

THE more efficient use of steel has most appeal in those industries, such as the automobile industry, where cheapness, lightness, and high resistance to the effects of repeated stresses are so important. Greater efficiency is achieved by (*a*) improved design to eliminate unnecessary weight, (*b*) cheaper steel, and (*c*) improved heat treatment practice.

Steels are intrinsically far stronger than we have conventionally assumed them to be, and the writer hopes to show in these notes that if we begin to think afresh about the hardening of steel and the nature of the stresses imposed upon machine parts in service, we shall benefit not just from greater efficiency in design, but from the very much easier machinability of " cheaper " steels. The metallurgist, when specifying the material for a machine part, often selects a steel which will give a reasonably uniform final hardness through its section after heat treatment. This has often meant that the alloying elements nickel, chromium, and molybdenum (singly or in combination) have been specified where none, in fact, was really necessary.

Tensile Strength and Hardness

It has been shown[1] that the Vickers hardness number (H_V) of an ideal plastic material is roughly three times its true yield stress (Y), i.e.—$H_V \simeq 3\ Y$ or $Y \simeq 0{\cdot}33\ H_V$. Further, since the nominal ultimate tensile strength (U_N) often happens to be the average true yield stress,[2] Y is essentially the same as U_N.

Hence, the Vickers diamond pyramid hardness gives a direct measure of the nominal ultimate tensile strength, by closely approximating to the relation :

$$U_N = 0{\cdot}33\ H_V$$

That the tensile strength of the soft (more ductile) steels is proportional to hardness has been known for many years. Where tensile strength is measured in kg./sq. mm., the factor has been found to be about 0·35, which is very close to that given above.[3] If it is assumed that this relation holds for the whole range of hardness, a graph such as that shown in Fig. 1 may be drawn. This relationship of hardness to tensile strength remains constant regardless of the structure of the steel, which is very convenient.

Another important property which has been found to be related to tensile strength is the endurance limit, which for specimens tested in rotating bending has been found to be $0{\cdot}5U_N$ (approximately)[4]. At hardness values above 350 this ratio is erratic,[5] the deleterious effects of stress-raisers becoming increasingly serious, so that an increase in tensile strength does not produce an equivalent proportional increase in endurance. For this reason, and because " hard " steels have very little toughness, there has been widespread opposition to the use of steels having tensile strengths in excess of about 140 kg./sq. mm. (90 tons/sq. in.). It is hoped to show that this opposition has been based on incorrect judgements of what properties are desirable in machine parts subjected to varying stresses in bending and torsion.

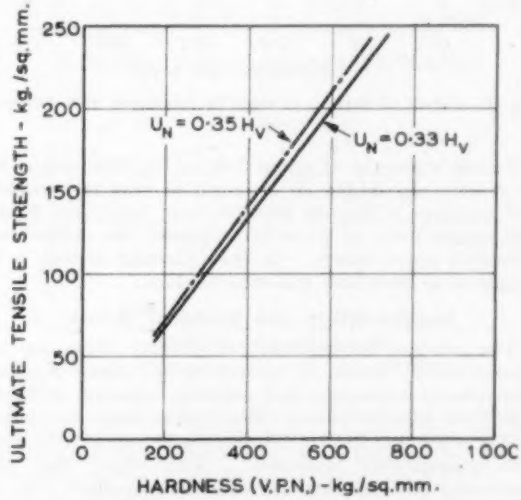


Fig. 1.—Relationship between ultimate tensile stress and Vickers diamond pyramid hardness.

It may be concluded, therefore, that hardness tests should provide a sufficiently accurate indication of tensile strength, but endurance is so dependent upon other factors, such as surface finish, and above all on residual internal stresses, that no reliable prediction is possible merely on the basis of tensile strength.

The Hardness of Quenched Steel

The hardness (and hence the tensile strength) of hardened steel is dependent almost entirely upon its carbon content, and not upon the amount of alloying element it contains. This is shown very clearly in Fig. 2, the graph indicating the maximum hardness attainable in steels of varying carbon content.[6] Two significant facts emerge from a study of this graph : namely that there is very little to be gained by employing steels with carbon contents in excess of about 0·45% (except for specialised applications such as high wear-resistance), and that the low-carbon martensites ought to be very useful engineering materials. This latter point is further confirmed by Fig. 3, which shows the hardness obtained on about twenty-five different alloy compositions containing varying amounts of nickel, chromium, molybdenum, and vanadium.[7]

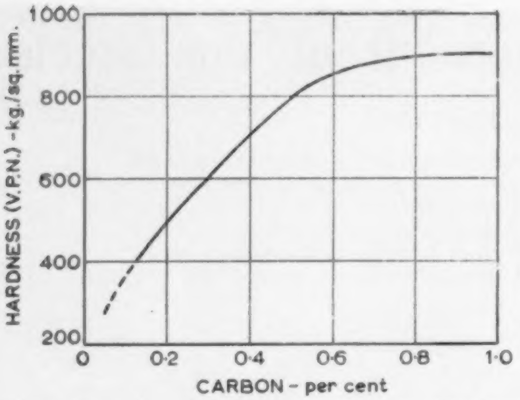


Fig. 2.—Effect of carbon content on hardness of hardened steel.

Tensile strengths of up to 250 kg./sq. mm. ought to be readily obtainable by appropriate heat treatments. The problem is how to provide these very hard steels with some form of protection against the deleterious effects of stress-raisers. In the following section it is proposed to show how this may be done.

Hardenability and Residual Stress

The relative hardenability of various steels can be quantitatively shown by quenching specimens of equal dimensions, sectioning, and plotting variation of hardness from edge to centre. The typical diagrams shown in Fig. 4 are for steels water quenched from 927° C., and not subsequently tempered.[8] They show that full hardening will not extend to much more than ⅛-in. in plain carbon steels, although the difference between surface and centre decreases as carbon content increases. The effect of alloying elements is still further to reduce this hardness differential between surface and centre, i.e. they increase hardenability.

When a steel is hardened it undergoes a diminution of density, i.e. for a given mass the volume increases. If the steel through-hardens, this volume increase merely appears as an increase in dimensions of the part being treated. If hardening occurs only at and near the surface, however, the natural volume increase is in part prevented by the underlying non-fully-transformed metal, and a stress system is introduced into the steel. The less the degree of transformation in the core, the greater will be the difference in density between the hardened zone and the inner core, and hence the greater the stress differential between the two. A compressive stress is set up in the hardened metal due to the core of the part preventing the natural expansion of this hard zone. A tension stress is of course generated in the core, and the relative values of the compression and tension stresses are dependent upon the relative dimensions of the hard zone and the underlying core, and upon the degree of transformation in each zone.

This hardness (or stress) differential can be made a maximum by heating only the outer surface of the metal, instead of depending upon the low hardenability of the steel to provide the necessary difference in final hardness of surface and core, and is best achieved by induction heating. Induction hardening results in a somewhat higher hardness than the conventional quench, so that residual compressive stresses in the hardened zone tend to be the maximum obtainable, and provides perfect reproducibility, a most important feature in high volume production. These compressive stresses will endow the hardened steel with the necessary cohesion to resist failure.

The Residual Stress Pattern and Externally Applied Stress

Suppose two steels of similar carbon content, but of widely differing hardenabilities are heat treated under identical conditions. Respective hardness distributions within the specimens will be somewhat as shown in Fig. 5. If there are compressive stresses in the outermost layers of the steel, internal equilibrium requires that at the same time there should be triaxial residual stresses in tension in the core. Any danger of consequent brittleness is avoided by having the core relatively ductile.

The strength of the outermost fibres in the high-hardenability steel (Fig. 5, *a*, *c*, *e*) is $T_H = T + C_H$, and the maximum value of the externally applied bending stress is $E_H = 0\cdot5\ T_H$, for indefinite life. In the case of the low-hardenability steel (for the same surface hardness), strength in the outermost fibres is $T_L = T + C_L$. It can readily be seen that T_L is greater than T_H, and therefore E_L can have a larger value than E_H (Fig. 5 *e* and *f*). A study of Fig 5*f* also shows that the effective tensile strength of the core is reduced by the tensile stresses brought into play by the compressive stresses produced during hardening. Where induction hardening is used to produce a hardness gradient from surface to core of a machine part, care must be taken to ensure that the correct balance between hard surface and ductile core exists.

When a steel is subjected to unit tensile stress, each element extends in the direction of the stress by an amount ϵ, while perpendicular to the stress the contraction is $\sigma\epsilon$ (where σ is Poisson's Ratio which has a value of about $0\cdot25$ for steel). Thus a minute but finite increase in volume occurs under stress, and those elements lying under the surface exert a mutual hydrostatic pressure upon one another. The spread of cracks from fissures, inclusions, or other "sore" spots within the body of the metal is therefore inhibited. No such protection occurs for those elements lying in the surface, and the writer advances this as one possible reason for the vulnerability of a surface to fatigue cracking.

Almen long ago recognised how much more vulnerable to fatigue the surface of a machine part is than its deeper

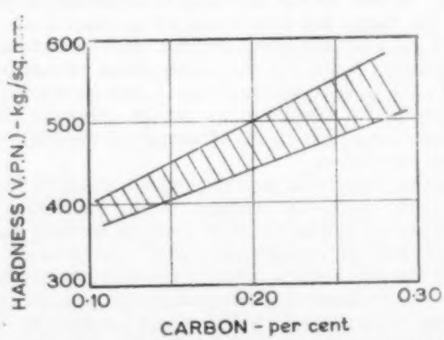


Fig. 3.—Band covering hardness values obtained on twenty-five hardened low-alloy steels containing varying amounts of nickel, chromium, molybdenum and vanadium.

layers. He succeeded in a most spectacular fashion in showing how this vulnerability could be reduced by shot-peening, although its effects extend for only a few thousandths of an inch into the material. He gave no explanation why this should be so, but stated merely: "It seems that the specimen surface is highly vulnerable simply because it is a surface."[9] Horger says: "It is conceivable that at and near the surface, where yielding and fracture by fatigue will be initiated, the crystal grains are less constrained by grain boundaries, than those situated further away."[9]

Discussion and Conclusions

It may be argued that high hardness will lead to lack of shock-resistance in a finished machine part processed as suggested in the foregoing. This is undoubtably true if a criterion such as the Izod test is used. To perform such a test, a specimen must be cut from the part under examination. The material is thus taken "out of its context," and the beneficial effects of a stress system under which it originally existed are lost. Neither does a machine part normally have the sharp notch required by the Izod test; in fact, such a notch would be considered extremely bad engineering practice.

Shock resistance, therefore, must be related to the machine part as a whole, and in the case where a part has its surface protected by high compressive stress it is the writer's opinion that the part will not show such a degree of brittleness as to preclude its safe and efficient functioning. Too long has the inherent high strength which can be developed in steels been wasted, because of the false view that brittleness goes hand in hand with high hardness.

One may take an example from one of the most brittle of materials. If glass is heated to near the plastic condition, and the outer surfaces of the piece then cooled quickly, these contract and solidify while the centre (inner core) is still viscous. A tensile stress then exists in the outer cooled surfaces, but as the core cools these stresses rapidly become zero, and finally become compressive when the core finally attains the same

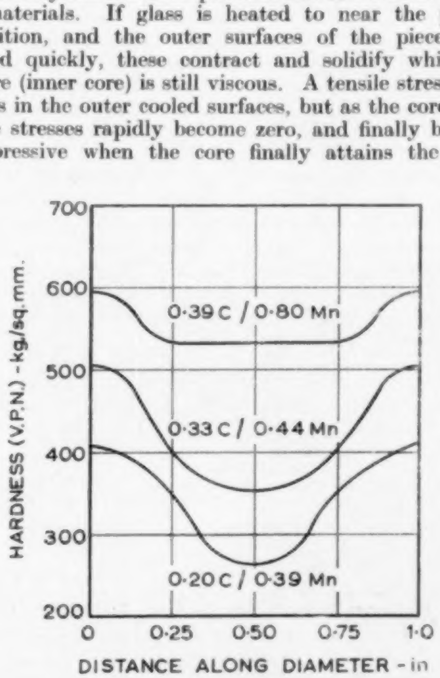


Fig. 4.—The relative hardenability of three steels containing different amounts of carbon and manganese. Original Rockwell hardness values have been converted to Vickers diamond pyramid hardness values.

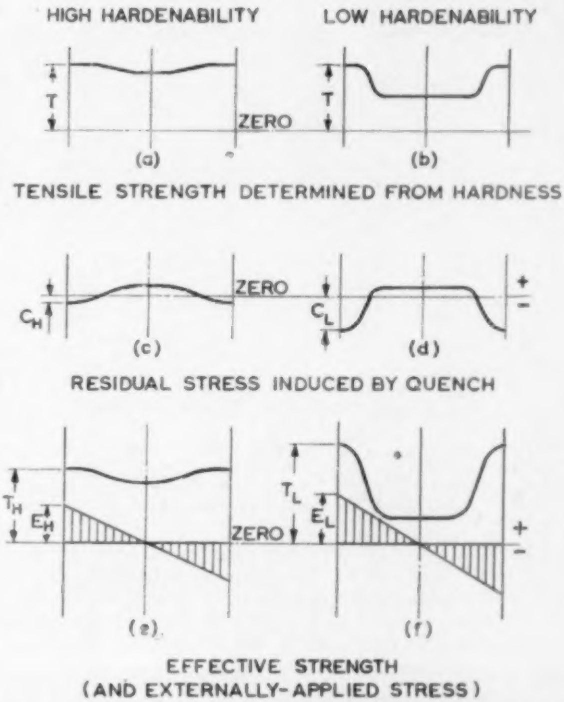


Fig. 5.—Variation of tensile strength, residual quenching stress and effective strength across the section of steels of high (left) and low (right) hardenability. The effective strength is the algebraic difference between the tensile strength deduced from hardness measurements and the residual stress induced by the quench.

temperature as the outer layers. It is well-known that such glass has increased mechanical strength and considerable elasticity as compared with normal glass. The compressive stresses induced into steel by heat treatment should increase endurance in reversed bending and torsion, and improve notch-resistance.

The metallurgical aspect of this problem of utilising high hardness is the development of the completely martensitic condition, i.e., the production of the maximum volume change between core and transformed surface. Induction hardening produces the hardest and most highly-dispersed martensite. An improvement in impact resistance of the hardened metal would probably be achieved by tempering at about 200° C., but it would be a matter of common prudence to avoid the "blue-brittle range" around 250° C.

The points already made may be set out as follows:—

(1) Steels of high hardness are intrinsically stronger than steels of lower hardness.

(2) At high hardness values, steels are more susceptible to fracture because they are more sensitive to stress-raisers.

(3) The harmful effects of these stress-raisers are inhibited by high compressive stresses.

(4) High compressive stresses can be developed to the depth required only by differential hardening effects depending upon low steel hardenability, selective hardening, or a combination of both (see Fig. 6).

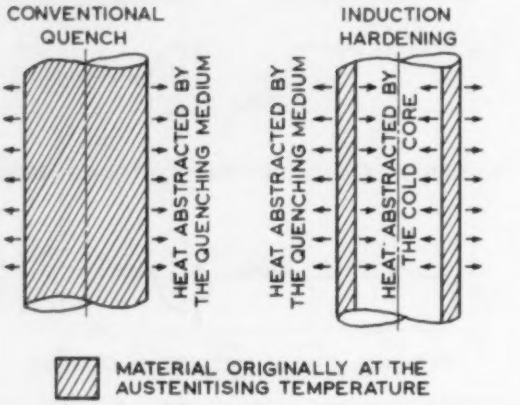


Fig. 6.—Diagram explaining the more efficient surface hardening resulting from induction heating: In conventional quenching all the heat from the core has to pass through the hardened surface.

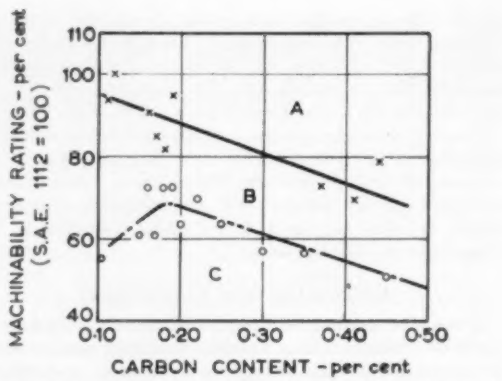


Fig. 7.—Comparison of machinability ratings for sulphurised and non-sulphurised steels. The crosses represent the sulphurised steels (0·075–0·15% S) and the circles non-sulphurised steels (0·055% S max.). A is a region of easy machining with good surface finish, C a region of difficult machining with relatively poor surface finish, and B a region of possible improvement.

(5) These compressive stresses, when correctly distributed, will enable machine parts to have a greater resistance to alternating bending and torsion than a similar part not possessing this internal stress system.

Several years ago a few exploratory tests were made at the writer's request in Vauxhall Motors Experimental Department, using induction-hardened passenger axle shafts.[13] Results under rotating bending were phenomenal as can be seen from the table :—

Bending Moment		905 lb. ft.
Equivalent Bending Stress		± 86,000 p.s.i.
	Induction Hardened and Tempered 320° C.	Induction Hardened only
Cycles to Failure	19,215/81,788	303,738/622,511
Surface Brinell	401/451	580

Unfortunately, the tests were discontinued after three determinations on " as-induction-hardened " shafts, but there can be no doubt as to the trend of results.

(6) Despite its high surface hardness, a part will have adequate resistance to shock in both bending and torsion where high surface compressive stresses are present, particularly if the inner core is relatively tough and ductile. Mechanical treatment such as shot-peening and cold rolling no doubt would still have a useful effect, because hard steels show a measure of plasticity and hence should be capable of being work-hardened.

If these conclusions are correct, it should be possible to employ not merely relatively shallow-hardening plain carbon steels in many highly-stressed applications, but also steels of a higher inclusion content than is common practice at present. The protective nature of the compressive stresses set up by heat treatment should permit this.

TABLE I.—EFFECT OF COMPOSITION ON IZOD IMPACT VALUE.

C	Si	Mn	P	S	Average Izod (ft. lb.)
0·200	0·036	0·55	0·065	0·067	6·7
0·245	0·059	0·61	0·049	0·051	15·2
0·242	0·071	0·63	0·043	0·040	25·5
0·246	0·105	0·60	0·038	0·039	51·7

Fig. 7 gives a comparison of the machinability ratings of sulphurised and non-sulphurised steels.[10] The question of machinability must inevitably become a factor of major importance where high-productivity transfer machines are employed. Good machining steels are soft and brittle,[11] and if Izod impact value is taken as a measure of this brittleness, it can be seen from Table I[12] how sensitive a steel is to sulphur and phosphorus content.

The area between the curves in Fig. 7 would undoubtably provide a fruitful field for research into machinability. Non-metallic inclusions have long been considered very harmful to fatigue life, but it may well be that where high compressive stresses are present, inclusion content can be greater without detracting from the serviceability of a machine part. The specification of both minimum and maximum limits for sulphur and phosphorus, instead of merely a maximum limit, would help materially in ensuring uniform machinability.

Greatly improved machinability, and less distortion during heat treatment, besides the main advantage of improved fatigue life could be the result of following in the procedure suggested in this article. One has merely to remember that a plain 0·3% carbon steel has a potential strength of at least 170 kg./sq. mm. (110 tons/sq. in.) to realise how great the gains can be.

Acknowledgment

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The Scope for Further Study of Anodic Oxide Films on Aluminium

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Some controversial aspects of the anodising of aluminium and of the sealing of the porous oxide film obtained by this method are discussed. Problems requiring further study include the mechanism of formation of porous films, ageing, absorption of dyes and coloured chemicals, pore closure by sealing, the chemistry of sealing and the criterion of adequate pore closure for corrosion-resistant applications.

IN a review published in 1959,[1] the author discussed prevailing views on the structure of porous anodic oxide films on aluminium before and after sealing. In the present paper, some aspects of this subject worthy of further investigation are indicated. The problems described range from the apparently purely academic to the practical.

Aspects for Study

The Theory of Formation of Porous Anodic Oxide Films

Any satisfactory theory must explain the nucleation of the pores in an approximately close-packed hexagonal array, their extreme regularity from the barrier layer to the outer surface, and the constant thickness of the barrier layer as the total film thickness increases at virtually constant voltage.

The studies of Franklin,[2] Stirland and Bicknell,[3] Altenpohl[4] and others on barrier-type films formed in neutral electrolytes appear significant in the first of these problems. These layers consist of a close-packed hexagonal distribution of oxide cells, the centres of which are amorphous Al_2O_3 and the outer regions crystalline γ'-Al_2O_3. In addition, the centres of the cells show the greater solubility in certain acid solutions. Consequently, it seems that, on anodising in an acid electrolyte, a barrier-type film is initially formed very rapidly, but on further contact with the acid the more rapidly soluble cell centres provide nuclei for the pores. Since these slightly thinner regions would carry most current, with consequent local heating, the pores initially nucleated might be expected to extend through the whole structure. The next step would appear to be to explain the fine structure of barrier-type films. An understanding of the influence of the local field conditions, the temperature and concentration of the electrolyte and the metal grain structure near the specimen/electrolyte interface in the initial and final stages of barrier layer formation is worth attempting.

In appreciating the reasons for the continuity and rate of growth of the porous structure, apart from the possibility of temperature and concentration rises at the pore bases, it is necessary to consider the relative mobilities of the cations and anions in the film. Although the marker experiments of Lewis and Plumb[5] may be interpreted as indicating that Al^{3+} ions constitute the most mobile species, Hoar and Mott[6] pointed out that OH^- ions may play an important part.

A more detailed discussion of this subject will appear elsewhere.[7] Although it may appear at first sight as only a fascinating academic problem, a closer understanding might lead to the possibility of forming thick films with fewer and smaller pores.

Films with Reproducible Properties—Ageing

It is becoming increasingly desirable to be able to specify the physical, chemical and electrical properties of anodic oxide films for various practical applications. At present, however, this is often impossible because the properties of films in a number of environments change with time. Examples of this phenomenon, known as 'ageing,' are given below.

(*a*) Booker and Wood,[8] measuring the variation in electrical impedance of films at various relative humidities with time, put forward a tentative explanation but pointed out that the mechanism is still not entirely understood.

(*b*) Films are less readily dyed after ageing.

(*c*) Sealing is slower if films are aged before the process is started. This subject will be discussed briefly elsewhere.[9]

(*d*) The properties of sealed films almost certainly change on exposure to the atmosphere and to certain solutions.

All these effects are probably inter-related but there is evidently a great deal of scope for work on films formed in a number of electrolytes and subsequently treated in a variety of ways.

The Mechanism of Absorption of Dyestuffs and Coloured Chemicals

The ability of unsealed and sealed films to absorb dyestuffs and coloured chemicals has aroused considerable interest recently.[10-13] Assuming it is small enough to enter a pore, a molecule or ion to be absorbed must be able to adsorb on a pore wall, and its capability of doing so depends on the electrical condition of the material forming the wall. In particular, it seems that the magnitude and sign of the zeta-potential in the double layer at the oxide/electrolyte interface in the pore may be the deciding factor. This subject and the influence of dyeing on the subsequent sealing rate require further study.

Pore Closure by Sealing

The sealing of porous anodic films in hot water or steam occurs by hydration of the quasi-amorphous or microcrystalline Al_2O_3 to give the less dense böhmite, AlO(OH). It is easy to understand how the surface layers become hydrated because of the close proximity

of the reactants, but the hydration of the inner layers is harder to visualise. Clearly, some mechanism involving the lattice transfer of ions, even if only over short distances, must be involved. It may be proposed tentatively[9] that protons and hydroxyl ions take an important part in the process.

The Chemistry of Sealing

Various mechanisms for the chemistry of the reactions between the oxide and sealing media such as nickel acetate solution, potassium dichromate solution, dichromate/chromate mixtures and sodium silicate solution have been suggested. Recent work[9,10] indicated that, although the nature, pH and conductance of the bulk electrolyte are obviously important, it is the properties of the electrolyte in the pores, and particularly at the pore side/electrolyte interface, that are vital. In examining the chemical reactions in more detail, the possibilities of new electrolytes should not be overlooked.

The Criterion of Complete Sealing

As a result of criteria based on the weight increase on sealing and the corrosion resistance of test panels of anodised metal, it has long been held that a sealing period of 30 minutes is adequate for most practical applications. Recent work by Hoar and Wood,[9,10] based on A.C. impedance measurements and colorimetric analysis, showed that the pores may not be completely closed even after sealing for 24 hours. An increased knowledge of the significance of the various testing methods is required.

Booker, Wood and Walsh[14] and Keller, Hunter and Robinson[15] demonstrated the regular nature of the pores of the unsealed structure by electron microscopy. It would be interesting to attempt to follow pore closure on sealing by this method, but replicating techniques permitting greater resolution than that obtained by the above investigators would be required for detailed work. Simultaneous gas adsorption studies would be a useful confirmatory method.

Anodised aluminium sealed in water is less resistant to corrosion if the operation is carried out at 80° C. rather than 100° C. This might be associated with the formation of a less compact or resistant form of böhmite, or even of bayerite, $Al_2O_3.3H_2O$, a thermodynamically more stable form of hydrated oxide at this temperature. Electron diffraction or X-ray diffraction data for films sealed for longer times at 80° C. would be of value.

In the quest for even better performance from anodised films in practice, particularly under severe corrosive conditions and where good electrical insulation is advisable, somewhat longer periods of sealing than the traditional 30 minutes might be advantageous. Tests in which degree of pore closure, corrosion resistance and mechanical strength are measured independently, as far as possible, should be employed.

Conclusion

Although the subjects of anodising and sealing have now received considerable attention, there are many interesting problems still to be solved. Very recent work in the literature shows that the theory of formation of porous films is the one attracting most workers at present.

Acknowledgments

The author wishes to thank Dr. T. P. Hoar and Dr. C. J. L. Booker for numerous discussions on the subject of anodising and the Aluminium Development Association for its interest and support.

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Steel in an Expanding Britain

continued from page 212

Again, the management problems involved in a change frighten many managers. The net result is a vicious circle in which the shortage of men caused by low productivity prevents the building of more productive equipment. "We need," said Sir Charles, "to release 50,000 men from low-productive parts of the coal industry, another 25,000 each from the railways and the steel industry, all of which could be done without serious loss, and use these men to build high-productivity capital equipment.

"This is a rich and well placed country, a land of opportunity. The prospects for steel for exports and for home use are good providing we are prepared to grasp the opportunities of this country as a whole and of the Commonwealth associated with it. We shall need to become more flexible and forward-minded and scrap our restrictive traditions. We shall need to stop wasting our basically plentiful resources. We shall have to appreciate more fully Britain's potential in the rapidly advancing world and get out of the habit of merely patting ourselves on the back for the progress we do make."

Forge Furnace Design

continued from page 238

controlled. This may be accomplished by a mechanical proportioning device at each burner, or the fuel/air ratio to the whole furnace may be accurately set by a proportioning controller.

Further Work

The thermal efficiency of a forge furnace is influenced by all these different features of furnace design and operation. The British Iron and Steel Research Association is now studying furnace performance, using a pilot scale forge furnace whose characteristics can be radically altered.

Further information on forge furnace design—including a detailed account of the tests carried out at Walter Somers Ltd. and a numerical method of evaluating temperature distribution—is contained in BISRA report PE/A/44/59. This report and any other relevant data may be obtained from the Information Officer, The British Iron and Steel Research Association, 11, Park Lane, London, W.1.

The Constitution of Quaternary Aluminium-Copper-Magnesium-Silicon Alloys at 500° C.

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The constitution of alloys containing 0–2% silicon, 0–4% magnesium and 0–4·5% copper has been studied by microscopical examination of alloys that had been severely worked and then annealed at 500° C. for four weeks. The phases occurring in this system are identical with those that occur in the constituent ternary systems but with, in addition, a quaternary phase which has been designated "Q." The form of the aluminium solid-solution region at 500° C. has been deduced from the determined sections of the isotherm. The shapes of the phase-fields in these sections have been shown to correspond satisfactorily with those determined from a consideration of the geometry of the phase-regions in the quaternary isotherm. Also, equations have been deduced which enable the approximate positions of certain phase boundaries in any section of the aluminium-rich corner of the system to be calculated.

ALL the phases which occur in the aluminium-rich corners of the constituent ternary systems occur in the Al-Cu-Mg-Si system also. These are the aluminium solid-solution (α), elemental silicon, and the compounds $CuAl_2$ (θ), $CuMgAl_2$ (S), and Mg_2Si. In addition, a quaternary phase "Q" is present. This was first recognised as being a distinct phase by Dix, Sager and Sager.[1] Petrov[2] stated that it had a formula of either $Al\,CuMg_4Si_4$ or $Al_5CuMg_5Si_4$, whilst Phragmen[3] discovered that it had a hexagonal structure and suggested that it could be better represented by the formula $Al_5Cu_2Mg_8Si_6$.

Schrader[4] has made a fairly comprehensive study of the form of the liquidus for the aluminium-rich corner of the Al-Cu-Mg-Si system. In addition to the eutectic and peritectic reactions which occur in the three constituent ternary systems, she listed seven quaternary reactions for which she had found evidence. Petrov and Nagorskaya[5] confirmed four of these quaternary reactions and in addition reported two others. Schrader[4] also determined three sections of the 490° C. isotherm at aluminium levels of 92%, 96% and 98%.

Axon[6–8] has determined three sections of the 460° C. isotherm for alloys having 0·6%, 1·2% or 2% silicon. These have been discussed critically by Collins[9] both from the theoretical and practical standpoints, and he has made slight alterations to two of the diagrams. He has also, at a later date, published[10] two sections of the 520° C. isotherm at 1·25% and 1·4% copper.

It is known that the aluminium solid-solution region is severely restricted at lower temperatures, and thus there is a considerable difference between the 460° C. and 520° C. isotherms, especially near to the region itself. No published information was available on the constitution of the Al-Cu-Mg-Si alloys at 500° C. This temperature was selected by the author for the solution-treatment of the alloys in a parallel investigation of their age-hardening characteristics, work as yet unpublished.

Experimental Procedure

The alloys were made up from the purest materials available. Super-purity aluminium was used and the copper and silicon were added as hardeners, that is, as alloys with super-purity aluminium. The magnesium was added as the pure metal. Analysis of alloys picked out at random showed the true compositions were close to their nominal compositions. The only appreciable difference was in the magnesium content. The loss on dissolving magnesium in the melt usually resulted in a content 0·1% below the nominal composition. This loss was allowed for in plotting the isothermal sections.

The alloys were made up in Salamander crucibles which had been lined with a mixture of alumina with 7% fluospar to prevent contamination of the melt,[11] and since melting was carried out in an electric, vertical-tube furnace, there would be no danger of gas pick-up from furnace gases. The alloys were cast as ¼ in. diameter rods in a graphite mould, and a ½ in. length of each was taken and worked by pressing in order to break up the as-cast structure. Each specimen was then sealed in an evacuated, hard-glass tube to prevent oxidation during the annealing treatment. The annealing at 500° C. lasted for a minimum period of four weeks, after which the specimens were quenched as rapidly as possible into cold water at 20° C.

Specimens were mounted in batches in Diakon plastic and, after removal of the surface layers by turning in a lathe, were wet-ground on silicon carbide papers. After a final grind on the 600 grade paper the specimens were polished using 0–2μ diamond polishing compound, ordinary thin lubricating oil being used as a lubricant. When necessary, a final hand polish was given using fine magnesia.

All the phases could be seen in the unetched condition. Silicon was easily identifiable, as it was present as outlined slate-grey particles. The "Q" phase, similarly, was easily identifiable, as it was often present as lighter grey needles. In the unetched condition, the Mg_2Si phase generally appeared bright blue, though not invariably. Etching in a 0·5% hydrofluoric acid solution rapidly turned it to a dark brown or black colour. Both the S and θ phases appeared as white or faint pink outlined particles in the unetched state and could easily be confused with each other. However, on etching with a reagent consisting of a solution of 0·5% hydrofluoric acid, 1·5% hydrochloric acid and 2·5% nitric acid in water, the S phase rapidly turned dark brown, leaving the θ phase unattacked.

Representation of Quaternary Systems

The main method used to represent quaternary isothermal equilibria is by the use of a regular tetrahedron.

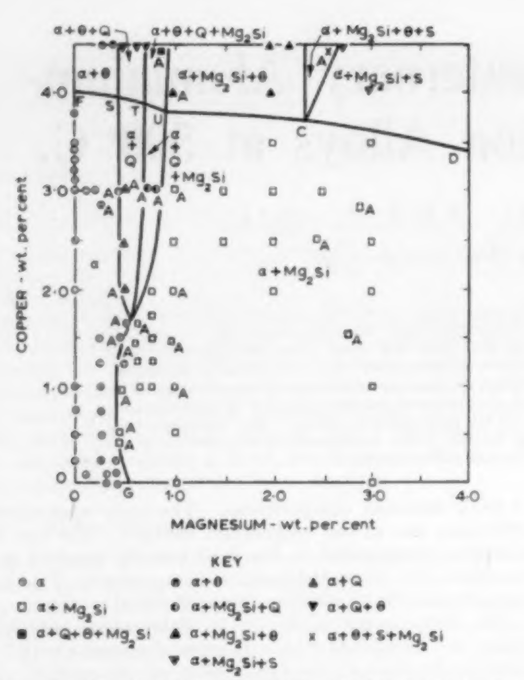


Fig. 1.—Section at 0·6% silicon of the 500° C. isotherm for the Al-Cu-Mg-Si system.

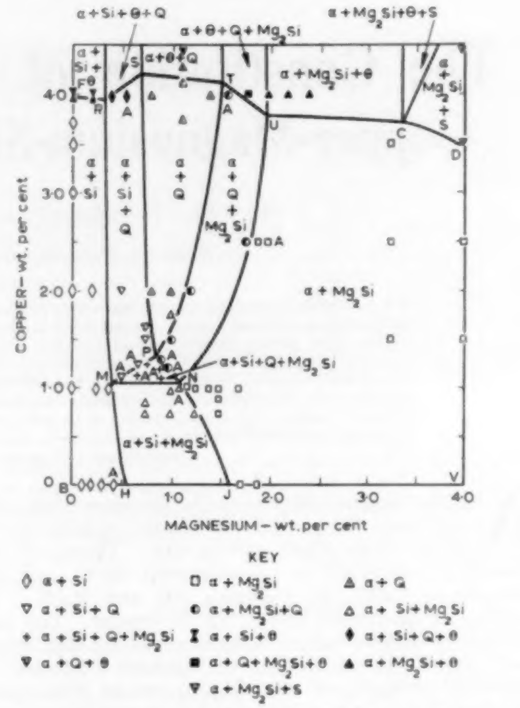


Fig. 2.—Section at 1·2% silicon of the 500° C. isotherm for the Al-Cu-Mg-Si system.

Each of the four faces is an equilateral triangle representing the isotherm of one of the four constituent ternary systems.

If the content of one component of a quaternary system be fixed, the isotherm will then be represented by an equilateral triangle which is a section through the concentration tetrahedron parallel to one face. In the present investigation, this scheme has been adopted, that is, the content of one of the components has been kept constant, so that the results could be plotted on two-dimensional diagrams.

As the investigation was concerned only with alloys containing relatively large amounts of aluminium, it was not necessary, in constructing the diagrams, to keep the axes at 60°. By plotting the results with the customary rectangular co-ordinates, comparisons with Axon's[6–8] and Collins'[9, 10] results were made easier.

Sections of the 500° C. Isotherm

In order that the constitution of the system could be represented on two-dimensional diagrams, alloys were prepared having one of three silicon contents—0·6%, 1·2% or 1·8%—or one of two copper contents—3% or 4·5%. In the constant-silicon sections the composition range covered was from 0 to 4·5% copper and from 0 to 4% magnesium, but in the constant-copper sections the constitution was only investigated for alloys containing between 0 and 2% of either magnesium or silicon.

Figs. 1, 2 and 3 are the 0·6%, 1·2% and 1·8% silicon sections as they have been plotted from the results of the present investigation. The relative position of the different phase-fields in Figs. 2 and 3 correspond with those in the three constant-silicon sections published by Axon,[6–8] though the fields themselves have extended along the direction of the magnesium axis to a slight

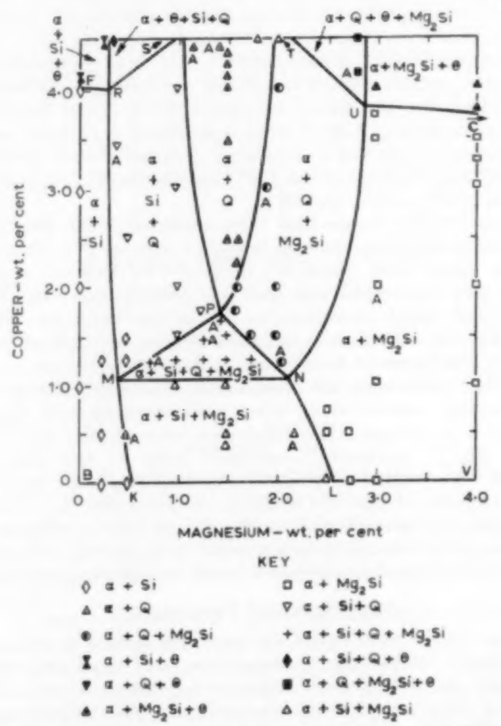


Fig. 3.—Section at 1·8% silicon of the 500° C. isotherm for the Al-Cu-Mg-Si system.

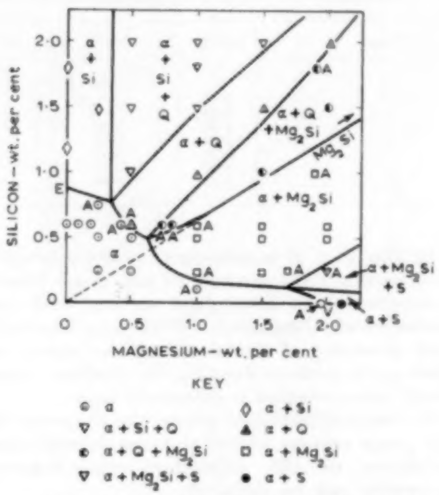


Fig. 4.—Section at 3·0% copper of the 500° C. isotherm for the Al-Cu-Mg-Si system.

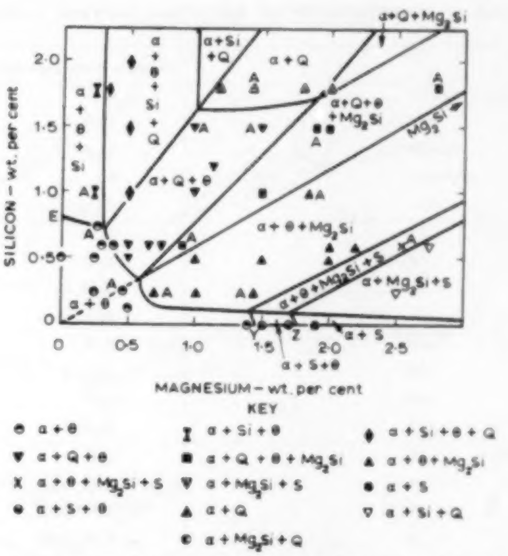


Fig. 5.—Section at 4·5% copper of the 500° C. isotherm for the Al-Cu-Mg-Si system.

extent. The 0·6% silicon section at 500° C. (Fig. 1) differs from the 0·6% silicon section at 460° C. published by Axon, in that silicon is not present as a phase itself. This is because the solid-solubility of silicon in aluminium at 500° C. is 0·8% and, therefore, it will all be in solution.

Figs. 4 and 5 are the 3% and 4·5% copper sections respectively of the 500° C. isotherm as they have been plotted from the experimental results. By comparing these two figures with the ternary Al-Mg-Si isotherm at 500° C. (Phillips[12]), it will be seen that the reduction of the solubility of silicon in the aluminium solid-solution on adding 0·25% magnesium is not nearly so great when the alloy contains 3 or 4·5% copper. Reference to the 1·4% copper section of the 520° C. isotherm published by Collins[10] shows that he has drawn the boundary between the ($\alpha+Mg_2Si$) and ($\alpha+Mg_2Si+Q$) fields along a line which is in the Al-θ-Mg_2Si plane. In Fig. 4, this could also be done, except that near the aluminium solid-solution field the boundary was hard to draw to fit in with the observed facts without deviating from this line.

Any four-phase region in a quaternary isotherm is bounded by the sides of a tetrahedron, and thus any section of such a region must have straight-line boundaries. The 4·5% copper section (Fig. 5) cuts three such regions, and thus the boundaries of the three four-phase fields in the section have been drawn as straight lines. One consequence of this is that the boundary between the ($\alpha+Q+Mg_2Si+\theta$) and ($\alpha+Mg_2Si+\theta$) fields follows exactly the line in the Al-θ-Mg_2Si plane, that is, the line marked "$Mg_2Si\rightarrow$" in Fig. 5.

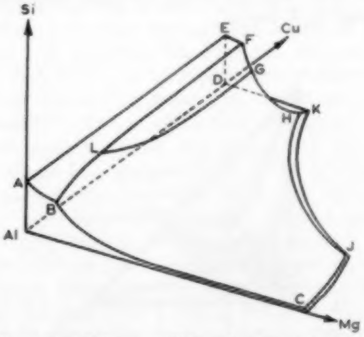


Fig. 6.—The aluminium solid solution (α) region in the Al-Cu-Mg-Si system at 500° C.

The Aluminium Solid-Solution Region

Axon[6–8] and Collins[9,10] have published diagrams to show the shape of the aluminium solid-solution region at 460° C. and 520° C., respectively. In the present investigation, the results are more in agreement with Collins' diagram.

In Fig. 6 is shown the form of the region at 500° C., as determined from the present results. The points A, D and C are taken from the constituent binary systems, the points B, E, K and J from the constituent ternary systems, and the positions of the points F, G, L and H have been estimated as outlined below.

A face on the α solid-solution region represents the equilibrium between α and one other phase, a line represents the equilibrium between α and two phases, whilst a point represents the equilibrium between α and three other phases. The various equilibria represented by the faces, lines and points on the surface of the α region in Fig. 6 are summarised in Table I.

The point F, therefore, represents the equilibrium between α, Q, θ and Si, and its position is where the ($\alpha+Q+\theta+Si$) region contracts to a point and meets the α region (Fig. 9*c*). By reference to Figs. 2, 3 and 5, this point was estimated as occurring at a composition of 4% copper, 0·3% magnesium and 0·77% silicon.

Similarly, the point G occurs where the ($\alpha+Q+\theta+Mg_2Si$) region comes to a point and meets the α region (Fig. 9*e*). From Figs. 1, 2, 3 and 5 its position was estimated as being 3·85% copper, 0·6% magnesium and 0·35% silicon.

The point H occurs where the ($\alpha+Mg_2Si+\theta+S$) region meets the α solid-solution region, and its position is determined by the position of the point corresponding to C in Figs. 1 and 2, when the silicon content has been

TABLE I.—REPRESENTATION OF EQUILIBRIA BETWEEN α SOLID-SOLUTION AND OTHER PHASES

		Phases in Equilibrium with α
Face :	*ABLFE*	Si
	FGL	Q
	CBLGHJ	Mg_2Si
	DEFGHK	θ
	HKJ	S
Line :	*EF*	Si, θ
	LF	Si, Q
	LG	Mg_2Si, Q
	BL	Mg_2Si, Si
	FG	Q, θ
	GH	Mg_2Si, θ
	HK	S, θ
	HJ	Mg_2Si, S
Point :	*F*	Q, θ, Si
	G	Q, θ, Mg_2Si
	H	S, θ, Mg_2Si
	L	Si, Q, Mg_2Si

reduced sufficiently for all the Mg_2Si phase just to disappear (Fig. 9*g*). The phase boundaries of this region have not been bracketed well in the present work, and an estimate of the position of *H* must necessarily be rough. According to Collins' work,[9,10] the solubility of magnesium in an Al-Cu-Mg alloy is unaffected by small additions of silicon, but in the present work it was found necessary to draw this solubility line to represent a slight decrease (Figs. 4 and 5). So the magnesium composition of the point *H* was estimated at 1·4%, representing a slight decrease from the 1·5% of the point *K* in the ternary Al-Cu-Mg system. The copper content was judged to be approximately 3·7% and the silicon content was very small and thought to be about 0·05%.

The point *L* occurs where the four-phase region (α+Si+Q+Mg_2Si) meets the α region. This is where the triangular field, as it occurs in the constant-silicon sections (Figs. 2 and 3), is reduced to a point (Fig. 8*d*). The corner *M* of this triangle occurs at 0·4% magnesium and 1·05% copper in both sections. Thus the point *L* will have these same copper and magnesium compositions, and the silicon composition has been estimated by extrapolation of the other two corners of the triangle.

The compositions of the points in the aluminium solid-solution region in Fig. 6, established values taken from the binary and ternary systems, and those estimated above, are summarised in Table II.

Solid Geometry of the Phase Regions in the Quaternary Isotherm

In constructing sections of a quaternary diagram at constant levels of one of the components, such as the constant-silicon and constant-copper sections described above, it is very desirable to build up a picture of the shapes of all the relevant phase-regions in the tetrahedral model. If this can be done, the shape of each of the phase-fields in any plane section through the model can be deduced, and compared with the shape of the corresponding field in the experimentally-determined section. In this way, it is sometimes possible to estimate with fair accuracy the position of any phase boundary, in an experimentally-determined section, that has not been satisfactorily bracketed. Without a knowledge of the solid geometry of the phase regions, serious errors are liable to be made in drawing the sections unless the number of alloys studied is extremely large.

TABLE II.—COMPOSITION OF POINTS IN THE α SOLID-SOLUTION REGION

Point	Cu %	Mg %	Si %
A	—	—	0·80
B	—	0·55	0·60
D	4·00	—	—
E	4·00	—	0·80
F	4·00	0·30	0·77
G	3·85	0·60	0·35
H	3·70	1·40	0·05
K	3·90	1·50	—
L	1·05	0·40	0·77

By the method described below, the shapes of all the relevant phase regions, and of sections through them, in the isotherm of the aluminium-copper-magnesium-silicon system can be deduced.

Assuming that the individual phases, Si, Mg_2Si, θ, S and Q have definite compositions, without appreciable solid-solution ranges, a simple model can be constructed showing the relationship of these phases to the aluminium-rich corner of the system. This is shown in Fig. 7, which is taken from Collins' paper.[10] In this figure, a two-phase region is represented by the rod joining the two phases concerned. A three-phase region is represented by a triangular lamina which is bounded by the three rods joining the three phases concerned. A four-phase region is represented by a tetrahedron whose six edges are the six rods joining the four phases concerned.

By considering each of the various faces, lines and points on the α solid-solution region (Fig. 6), and joining them to the appropriate phases shown in Fig. 7, perspective diagrams can be constructed showing the theoretical shapes of all the phase regions extending from the aluminium-rich corner of the tetrahedral model. Thus, all the corners of a given face in Fig. 6 are joined to the phase with which α is in equilibrium, as given in Table I. For example, the points *A*, *B*, *L*, *F*, *E* on the uppermost face of Fig. 6 are joined to the point representing the Si phase. Similarly, each end of any given line in Fig. 6 is joined to each of the two phases with which the α is in equilibrium, as given in the same table. Each point in Fig. 6 is similarly joined to each of the three phases with which the α is in equilibrium. Results obtained in this way are described below.

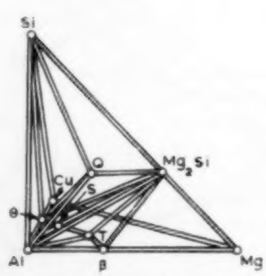
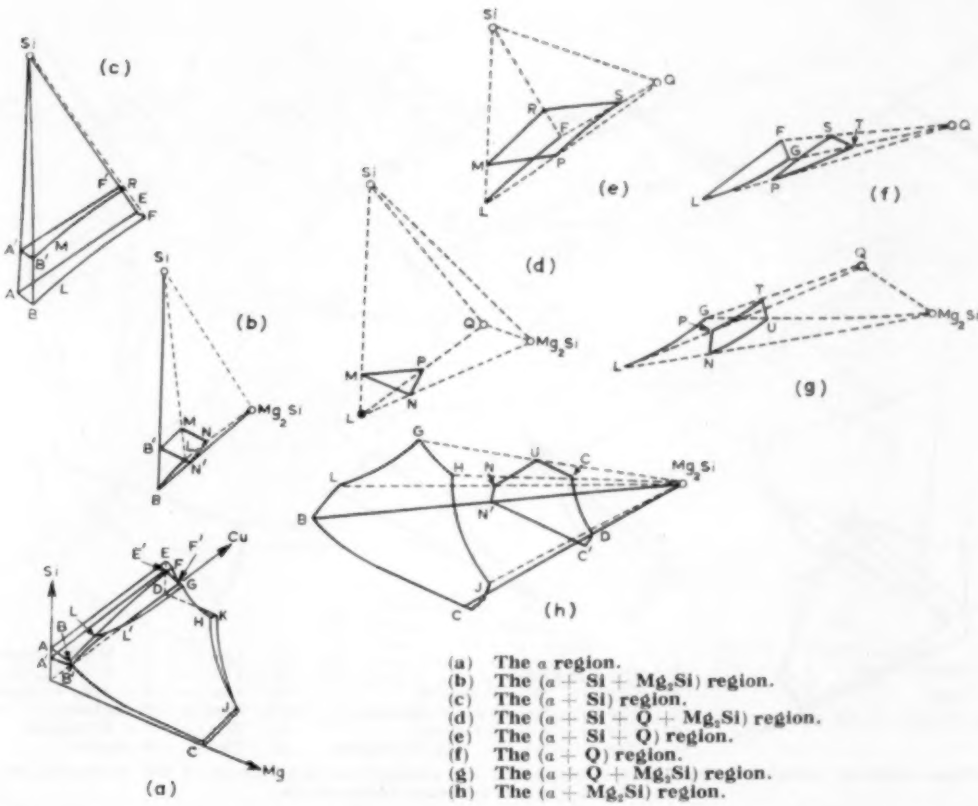


Fig. 7.—The distribution of phase-regions in the aluminium-rich corner of the Al-Cu-Mg-Si system.



(a) The α region.
(b) The (α + Si + Mg_2Si) region.
(c) The (α + Si) region.
(d) The (α + Si + Q + Mg_2Si) region.
(e) The (α + Si + Q) region.
(f) The (α + Q) region.
(g) The (α + Q + Mg_2Si) region.
(h) The (α + Mg_2Si) region.

Fig. 8.—Phase-regions, excluding those containing the θ and S phases, in the aluminium-rich corner of the Al-Cu-Mg-Si system, showing the sections at constant silicon levels.

It must be emphasised that in these perspective diagrams, as they have been drawn in Figs. 8–11, the heights and extents of the faces and lines on the α solid-solution region have been much exaggerated compared with the distances to the phases. Thus the sections of the phase regions will be distorted.

Sections of Phase Regions at Constant Silicon Contents

Figs. 8 and 9 give the perspective diagrams of all the phase regions extending from the α solid-solution region, which is shown in Fig. 6 and repeated in Figs. 8*a* and 9*a*. In each case, a section through the region at a constant silicon level is shown. In Fig. 8*a*, for example, the section *A'B'L'F'E'* is at a silicon level below the solubility limit of silicon in aluminium, and it therefore has a shape similar to that of the α field in Fig. 1.

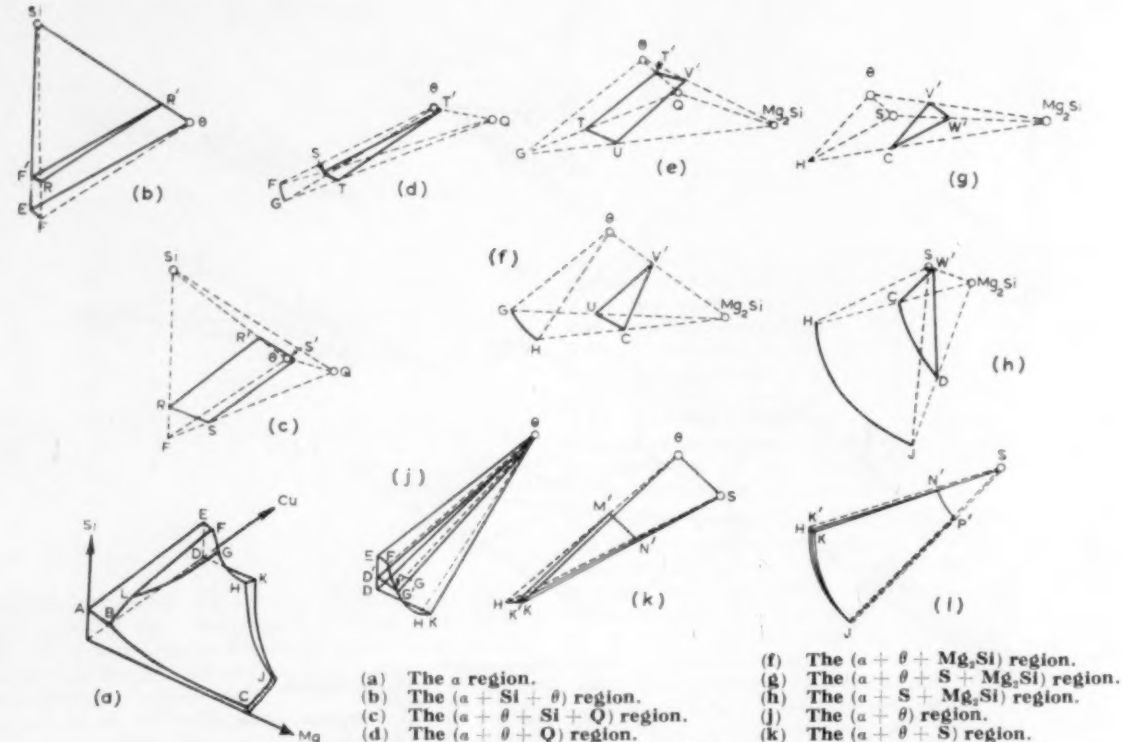
Figs. 8*b* and 8*h* show the shapes of the constant-silicon sections, at a higher silicon level, of regions which contain one or more of the phases Si, Q and Mg_2Si Fig. 8*b*, for instance, shows the shape of the (α+Si+Mg_2Si) region, which is tetrahedral. *B'MNN'* is a section of it at a constant silicon level of, say, 1–2% and its shape therefore corresponds to that of the field marked *HMNJ* in Fig. 2 and *KMNL* in Fig. 3. Similarly, Fig. 8*c* shows the shape of the (α+Si) region, and the section *A'B'MRF'* has a shape similar to that of the (α+Si) field *BHMRF* in Fig. 2, and *BKMRF* in Fig. 3.

Taking one further example, Fig. 8*h* shows the (α+Mg_2Si) region, and the section *C'N'NUCD* has a shape similar to that of the (α+Mg_2Si) field *VJNUCD* in Fig. 2.

The shapes of the sections of all the other phase regions shown in Fig. 8 are similar to those of the corresponding fields in Figs. 1–3.

In Fig. 9 the remaining phase regions, with sections at constant silicon levels, are shown. In Figs. 9*b*–9*f* the shapes of five sections shown are alternately triangles and trapeziums. Bearing in mind that the lines of the α region have been exaggerated compared with the distances to the phases, it will be realised that these five sections should be long, thin triangles or long, thin trapeziums, the long sides of which should tend to be parallel to the aluminium-copper axis. Reference to Figs. 1, 2 and 3 shows that these five fields, as they appear in constant-silicon sections, do have sides parallel to the aluminium-copper axis.

Fig. 9*g* shows the four-phase region containing α, θ, S and Mg_2Si. The edges of this region are all straight lines, and thus any section of it will have straight sides. It can be seen that sections at constant-silicon levels will be triangular and geometrically similar. Fig. 9*h* shows the constant-silicon section of the (α+Mg_2Si+S) region. Fig. 9*j* shows the (α+θ) region: this would only be cut by constant-silicon sections at silicon contents of less than



(a) The α region.
(b) The (α + Si + θ) region.
(c) The (α + θ + Si + Q) region.
(d) The (α + θ + Q) region.
(e) The (α + θ + Q + Mg_2Si) region.
(f) The (α + θ + Mg_2Si) region.
(g) The (α + θ + S + Mg_2Si) region.
(h) The (α + S + Mg_2Si) region.
(j) The (α + θ) region.
(k) The (α + θ + S) region.
(l) The (α + S) region.

Fig. 9.—Phase-regions containing the θ and S phases in the aluminium-rich corner of the Al-Cu-Mg-Si system showing the sections at constant silicon levels.

the solubility limit of 0·8%. Such a section, $D'G'\theta$ is shown to have a similar shape to that of the portion of the ($\alpha+\theta$) field shown in Fig. 1. The two remaining diagrams, Figs. 9*k* and 9*l* show the ($\alpha+\theta+$S) and ($\alpha+$S) regions, which can only occur in alloys with very low silicon contents, in which all the silicon is in solid-solution in the aluminium. The regions are, therefore, thin and plate-like, and constant-silicon sections, as shown, will have geometrically similar shapes to those of the same fields in the ternary Al-Cu-Mg system.

Sections of Phase Regions at Constant Copper Contents

In Figs. 10 and 11 the perspective views of the phase regions shown in Figs. 8 and 9 have been redrawn to show the shapes of the sections of these regions at copper contents of 3% and 4·5%, respectively. The eight phase-regions which are intersected by the 3% copper section are shown in Fig. 10, and it will be noted that the sections have the same shapes as the corresponding phase-fields in Fig. 4.

The phase-regions which are intersected by the 4·5% copper section have been drawn in Fig. 11. There are three four-phase regions (Figs. 11*c*, 11*e* and 11*g*), bounded by tetrahedra, and any section of these regions must have straight-line boundaries. This is shown by the sections drawn, and is in agreement with the shapes of the corresponding fields in the 4·5% copper section (Fig. 5). In fact, the shapes of all ten phase-fields drawn in Fig. 11 are the same as those in the 4·5% copper section.

TABLE III.—COMPOSITION OF CORNERS OF TRIANGULAR FIELD CUT BY 1·2% AND 1·8% SILICON SECTIONS OF THE (α + Mg_2Si + Si + Q) REGION

Si %	Point M		Point N		Point P	
	Cu %	Mg %	Cu %	Mg %	Cu %	Mg %
1·2	1·05	0·40	1·05	1·12	1·30	0·85
1·8	1·05	0·40	1·05	2·10	1·73	1·43

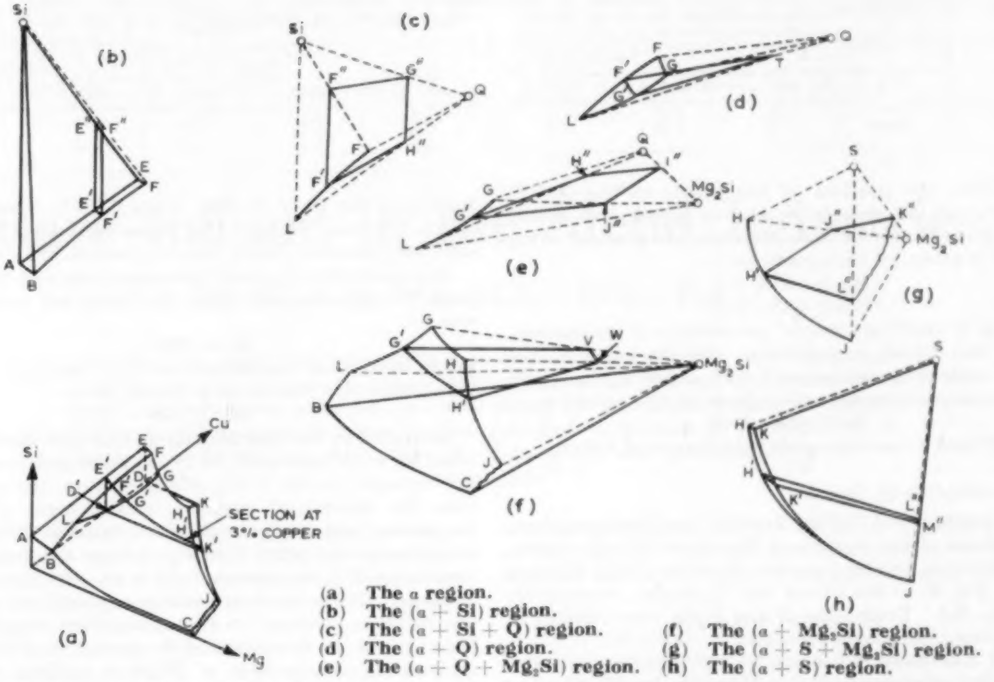
The Position of the Four-Phase Regions

As just stated, any four-phase region in a quaternary isotherm is a tetrahedron. This has straight sides and any section through it will have straight-line boundaries. Thus, simple equations can be deduced which will give the position of the four-phase field boundaries in sections of the aluminium-rich corner of the isotherm. It must be emphasised that these equations are not intended to enable one to plot accurate sections of the quaternary isotherm, but to enable approximate positions of some of the phase-field boundaries to be obtained. These could then be verified by a small amount of practical work, as outlined earlier in this paper.

The ($\alpha+Mg_2Si+Si+Q$) Region

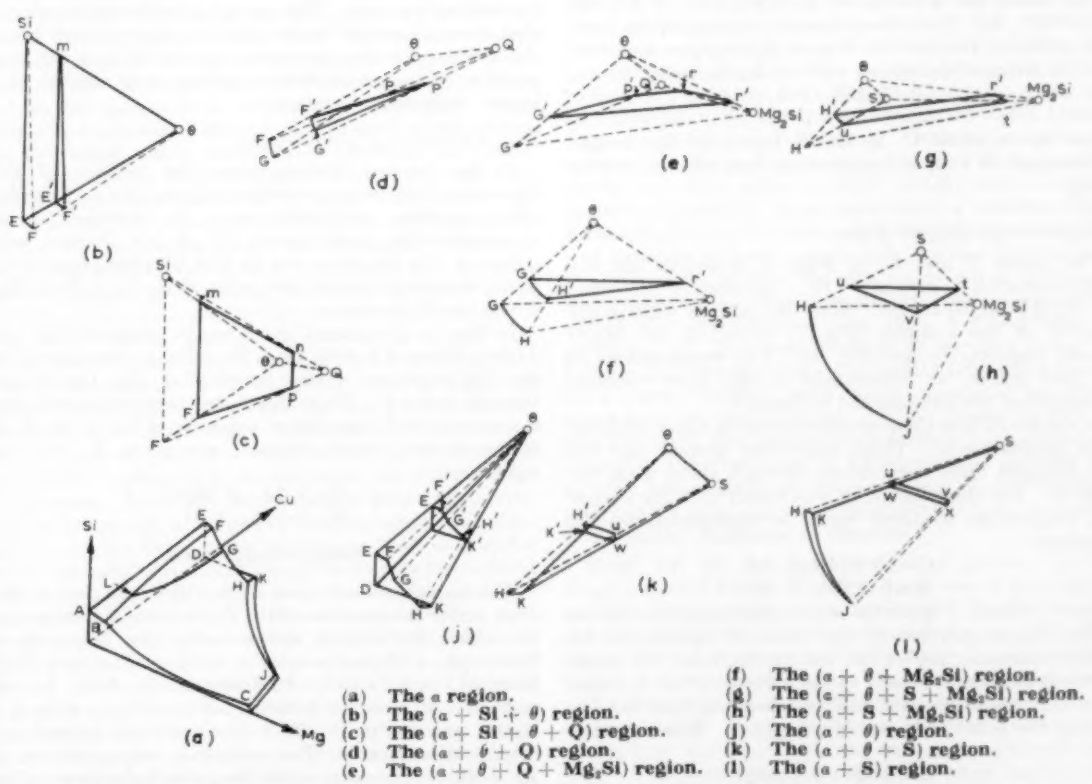
This region is cut by the 1·2% and 1·8% silicon sections (Figs. 2 and 3): It exists as a triangular field *MPN* in both. The composition of the three corners of this field in the two sections are given in Table III. The point *M*, therefore, occurs at the same copper and magnesium contents in any section taken at a low silicon level.

The loci of the corners, *P* and *N*, are the lines joining the point *L* in Fig. 6 to the *Q* and Mg_2Si phases (see Fig.



(a) The α region.
(b) The (α + Si) region.
(c) The (α + Si + Q) region.
(d) The (α + Q) region.
(e) The (α + Q + Mg_2Si) region.
(f) The (α + Mg_2Si) region.
(g) The (α + S + Mg_2Si) region.
(h) The (α + S) region.

Fig. 10.—Sections at 3% copper of the phase regions in the aluminium-rich corner of the Al-Cu-Mg-Si system.



(a) The α region.
(b) The (α + Si + θ) region.
(c) The (α + Si + θ + Q) region.
(d) The (α + θ + Q) region.
(e) The (α + θ + Q + Mg_2Si) region.
(f) The (α + θ + Mg_2Si) region.
(g) The (α + θ + S + Mg_2Si) region.
(h) The (α + S + Mg_2Si) region.
(j) The (α + θ) region.
(k) The (α + θ + S) region.
(l) The (α + S) region.

Fig. 11.—Sections at 4·5% copper of the phase-regions in the aluminium-rich corner of the Al-Cu-Mg-Si system.

TABLE IV.—COMPOSITION OF ALUMINIUM-RICH CORNERS OF THE 1·2% AND 1·8% SILICON SECTIONS OF THE ($\alpha+\theta+Si+Q$) REGION

Si %	Point *R*		Point *S*	
	Cu %	Mg %	Cu %	Mg %
1·2	4·00	0·30	4·20	0·71
1·8	4·00	0·30	4·56	1·03

8*d*). Thus, the position of the points in the 500° C. isotherm can be calculated at any given low silicon level. From the above measurements, the position of the point *P* is given by the equations :—

$$M=S-0\cdot37$$
$$C=0\cdot68S+0\cdot50$$

where M, C and S are weight percentages of magnesium, copper and silicon, respectively. For the point *N*, the copper content is constant at 1·05% at low silicon levels, and the magnesium content is given by the equation :—

$$M=1\cdot65S-0\cdot87$$

where M and S have the same significance as before.

The ($\alpha+\theta+Si+Q$) *Region*

The points *R* and *S* (Figs. 2 and 3), the two aluminium-rich corners of the sections of the ($\alpha+\theta+$Si$+$Q) region, lie on the lines joining the point *F* on the α solid-solution region (Fig. 6) to the silicon and Q phases, respectively (see Fig. 9*c*). From Figs. 2 and 3 the compositions of these points have been tabulated in Table IV.

Thus, the point *R* occurs at the same copper and magnesium contents at all low silicon levels. The locus of the point *S* will also pass through the point *F* on the α region which has a composition of 4% Cu ; 0·3% Mg and 0·77% Si. From these results, two equations have been deduced to give the copper and magnesium contents in terms of the silicon content for the point *S*.

$$C=0\cdot52S+3\cdot6$$
$$M=0\cdot78S-0\cdot3$$

where the symbols C, M and S represent the weight percentages of copper, magnesium and silicon, respectively.

The ($\alpha+\theta+Q+Mg_2Si$) *Region*

The points *T* and *U*, in Figs. 1, 2 and 3, are the aluminium-rich corners of sections of the ($\alpha+\theta+$Q$+Mg_2Si$) region. They lie on lines joining the point *G* on the α region (Fig. 6) to the Q and Mg_2Si phases, respectively (see Fig. 9*e*). The compositions of the two points, as determined in the three sections investigated, are summarised in Table V.

It was found that these results did not fit linear relationships satisfactorily. Thus, they were plotted and the best straight lines were drawn through them from the point *G*. For the point *T*, it was found that the copper and magnesium contents could be represented by the equations :—

$$C=0\cdot472S+3\cdot65$$
$$M=0\cdot927S+0\cdot25$$

where C, M and S have the same significance as before.

The copper content of the point *U* appears to be almost constant, but as the boundaries near this point were not bracketed closely in the sections (Figs. 1, 2 and 3), a theoretical equation has been deduced from the line joining the point *G* to the Mg_2Si phase. This equation is :—

$$C=3\cdot89-0\cdot1063S$$

It gives copper values, for the point *U* ranging from 3·85% at the point *G* (Fig. 6) to 3·70% when 1·8% silicon has been added. The values estimated theoretically are, therefore, fairly close to those in the diagrams.

TABLE V.—COMPOSITION OF ALUMINIUM-RICH CORNERS OF THE 0·6%, 1·2% and 1·8% SILICON SECTIONS OF THE ($\alpha+\theta+Q+Mg_2Si$) REGION

Si %	Point *T*		Point *U*	
	Cu %	Mg %	Cu %	Mg %
0·6	3·87	0·72	3·78	0·92
1·2	4·12	1·53	3·77	1·97
1·8	4·65	1·94	3·76	2·86

An equation to represent the magnesium content of the point *U* was calculated from the tabulated results and was :—

$$M=1\cdot59S$$

From theoretical considerations only, however, it was found that this relationship should be :—

$$M=1\cdot73S$$

Reference to the diagrams shows that this discrepancy is too big to be accounted for by experimental error alone. For example, in the 1·8% silicon section, the point *U*. from the theoretical equation, should occur at 3·1% magnesium instead of the observed value of 2·86%. In actual fact, near point *U* in Fig. 3 there are three alloys containing 3% magnesium which do not contain the Q phase. There are two possible explanations of this. One is that, contrary to the assumption made at the beginning of the discussion of the geometry of the phase regions, the composition of Mg_2Si is variable over an appreciable range. The experimental values suggest that the Mg_2Si contains an excess of 2·8% silicon above its nominal amount. The second possible explanation is that these alloys did contain the Q phase, though not in the sections of the specimens examined, and the true position of the phase-field boundary may well be at a higher magnesium content.

The ($\alpha+\theta+S+Mg_2Si$) *Region*

In the present investigation, the position of this region has only been located experimentally in the 0·6% silicon section, and even there the position of the aluminium-rich apex (point *C*) is not known with accuracy. In Fig. 9*g*, it can be seen that the locus of this point is the line joining the point *H* on the α field (Fig. 9*a*) to the Mg_2Si phase.

In Fig. 1, the point *C* is shown to occur at 0·6% Si, 2·33% Mg and 3·65% Cu. By joining the point *H* to the Mg_2Si phase, it was found that this line passed through point *C*. From this it has been calculated that the copper and magnesium contents of the point *C*, in terms of the silicon content, are given by the two equations :—

$$C=3\cdot71-0\cdot101S$$
$$M=1\cdot71S+1\cdot31$$

Acknowledgments

This paper is based upon work which was part of that done under the auspices of the University of London and for which the author was awarded the Doctorate of Philosophy. The author wishes to thank Professor C. W. Dannatt, and latterly Professor J. G. Ball, for the provision of research facilities at the Royal School of Mines, and also to Dr. M. S. Fisher for his interest and helpful discussions. The author is also indebted to Mr. J. H. G. Thomson of the Research Laboratory of the British Aluminium Co., Ltd., for the chemical analyses.

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Rare Indium in the Metal Industries

By M. Schofield, M.A., B.Sc., F.R.I.C.

Indium is one of the metals discovered as a result of the introduction of the flame spectrometer just over a hundred years ago, but until as late as 1924 indium continued to be regarded as such a rare metal that the world's supply was probably little more than a gram. Although still comparatively rare, indium now finds application in electroplating, in bearings, in low melting point alloys, in dental alloys, and in solders for use in the electrical field.

FOLLOWING the invention of the spectroscope or the flame spectrometer in 1859 by Bunsen and Kirchhoff, a number of new elements literally came to light, metallic elements which had escaped detection by ordinary chemical analysis. Caesium and rubidium were two of the first which made their debut in 1860, with Bunsen's caesium yielding a blue spectrum line and rubidium following with deep red bands in the spectrum. Sir William Crookes followed this work with the discovery of thallium, while in 1863 came a rarer metal found to be present in some zinc blendes, an element named " indium " because of its brilliant indigo spectrum line. While of these elements thallium with its toxic nature has found little commercial application apart from a few occasional alloys and salts used in rat poison, the two alkali metals rubidium and caesium are undergoing appreciable development due to their marketing by the American Potash and Chemical Corporation. So too there has been considerable attention paid to indium, particularly in bearing alloys, where indium has proved so advantageous that it has been suggested that no vehicle should speed along the London-Birmingham " M.1 " motorway unless fitted with indium bearings.

It was a fruitful partnership between Kirchhoff and Bunsen which brought the discovery of such new elements from 1860 onwards. With the newly-discovered Bunsen burner replacing the old spirit lamp, there came not only Bunsen's invaluable flame tests, tests which every student uses in qualitative analysis for detecting alkali and alkaline earth metals, but improved use of the spectra of elements. Kirchhoff used a hollow prism filled with carbon disulphide, a simple viewing-telescope and collimator, and the flame spectrometer was born as a useful aid to chemists and metallurgists as well as to physical science. A hundred years ago came the first demonstration of such value when Bunsen searched for a new alkali metal in mineral waters from Durkheim, and after evaporating tons of the water and removing calcium and strontium, found two blue lines of his new king of metals he called " caesium." A year later a second alkali metal was added to the list begun by Davy, this when the two partners examined a lepidolite from Saxony and unearthed rubidium, named thus from two red lines in the spectrum. Crookes added to the score with his thallium in residues deposited in a vitriol plant at Tilkerode in 1862, and then came indium in 1863 to continue the harvest won by use of Bunsen's technique.

Freiberg Discovery

Indium owes its discovery to Ferdinand Reich, professor and inspector at the famous Freiberg School of Mines, in collaboration with his assistant Theodor Richter. Reich was in charge of the mineral collections and was particularly interested during the eighteen-sixties in zinc ores from a Swedish mine. During his analyses he obtained a yellow precipitate of what seemed to be a new element ; hence he set Richter to carry out an examination by the spectroscope since Reich himself was colour-blind. The young German metallurgist tested some of the zinc ore with Bunsen's flame spectrometer and first noted a vivid indigo line, a colour invisible in ordinary flame tests using a platinum wire. Although Richter became noted for his expert assaying and blowpipe analysis, and despite the fact that he gave the impression that he was sole discoverer of indium, it was a joint affair. Not only did the two experimenters detect the new element, but they followed this by preparing the first crude sample of the free metal by heating in a blowpipe flame the metal oxide plus soda ash on a carbon block. Even more successful was their separation of indium from a zinc blende mined at Himmelsfurst, the indium oxide formed from a roasting operation being reduced in hydrogen and purified by melting below fused potassium cyanide. Later Richter's pure indium specimens were exhibited as a white ductile metal at the Academie of Sciences.

Reich left the full investigation of indium and its compounds to Clemens Winkler, discoverer of germanium and chemistry professor at Freiberg. Winkler in the *Journal für Praktische Chemie* in 1867 (page 273) described the reduction of the finely-divided oxide by thin layers or slices of sodium, the mass being pressed down and covered with a layer of sodium chloride. The porcelain crucible was placed in a Hessian crucible and cover, first heated gently, and then to a moderate red heat. The resulting brittle alloy was then boiled with water, washed with alcohol, and fused under a potassium

cyanide layer, this being followed by a final fusion with sodium carbonate.

In 1904 came one or two small-scale attempts to perfect an electrolytic process for indium, thus hinting at a modern process for plating. Dennis and Gear described in the *Berichte* for that year an electrolytic method using indium chloride or nitrate in solutions containing pyridine, hydroxylamine or formic acid, while later the sulphate was used in electrolysis. Yet even in 1924 indium continued to be regarded as such a rare metal that the world's supply of the metal was probably little more than a gram. In contrast, thanks to the Indium Corporation and to W. S. Murray and D. Gray in the United States, indium has now become available to meet any demands in commerce.

Extraction

Though indium is widely distributed in many ores, it usually occurs in proportions of less than 0·1% and is thus extracted only from zinc residues and smelter slags. The extraction processes vary according to the residues to be treated, a number of patent specifications illustrating the techniques used by American producers. The American Smelting and Refining Company of Denver, Colorado, first specified a recovery process[1] in which indium is precipitated as phosphate from an acid extraction of residues, the phosphate being converted to indium hydroxide and the metal then produced by reduction in hydrogen. In a second patent[2] for extracting from a zinc-lead raw material, the metal is melted with sodium chloride and lead chloride, a slag forming which includes the indium as chloride. After taking up the indium with dilute sulphuric acid, zinc dust is used to displace the indium, and chlorine to remove zinc from the zinc-indium product, the indium being refined electrolytically. This use of zinc for precipitating indium is also a feature of other recovery methods, as for example in a process used by the Cerro de Pasco Corporation of Oroya, Peru. Indium appears in the lead smelter series of operations in the concentrates and residues along with zinc, from which it goes into the lead bullion and is removed in drossing at a higher temperature than that used in removing copper. From a tin-indium residue after adding zinc and lead chloride, the indium is recovered as chloride in the slag. This is leached after adding acid, and zinc rods are used to bring down the indium as a sponge which by a purification process can yield 99·8% pure indium.

Yet another producer, the Anaconda Copper Mining Company of Great Falls, Montana, has protected a process[3] for indium extraction from zinc oxide fume formed in working up lead blast-furnace slag. The fume is extracted with very dilute acid to dissolve much of the zinc but leave indium in the residue, the latter now being dissolved by use of stronger sulphuric acid. Indium is precipitated by use of zinc oxide together with the sulphite and bisulphite of sodium, the indium being then re-dissolved, heavy metal impurities removed by hydrogen sulphide, and the indium sponge obtained by adding zinc being melted, cast and refined further by electrolysis. In one of the early processes of the Consolidated Mining and Smelting Company of Trail, British Columbia, indium was recovered from zinc oxide fume by leaching with dilute sulphuric acid, neutralising with soda to bring down a sludge, and extracting indium from this after removing heavy metals with hydrogen sulphide by use of zinc or aluminium for displacing the indium. A more modern process[4] used by the Cominco interests yields an indium slime from an electrolytic treatment using anodes of a bullion of lead, tin, copper and indium, the slime being worked up by a roasting process followed by leaching, with the indium finally precipitated by zinc or aluminium as before.

Applications

Turning now to the developments in applications of indium, the silver-white metal retaining its brightness on long exposure to the atmosphere became adopted in electroplating as an early example. The metal improves corrosion-resistance especially towards alkalies, while for surface protection of large steel surfaces, zinc-indium gives good results in resisting salt spray. Advantages claimed are non-porosity, no peeling or chipping, wear resistance, and good adhesion. In plating ferrous metals, a non-ferrous metal like zinc, copper or cadmium must be applied as base metal, the deposit being improved by diffusing the indium into the base metal by heating, this being essential in the major use of plating, viz. in the bearing field. Other examples in which indium is plated on a base metal are : as decorative finish, for hardening, for electrical contacts, and for producing transistor junctions. In bearing alloys first used in aviation and now in road transport the ideal put forward is to use silver-lead-indium, since silver resists failure due to fatigue, a thin lead layer adds " oiliness " to bearing surfaces, while a thin flash of indium deposited and then diffused into the lead increases strength, prevents corrosion due to organic acids liberated in use of lubricating oils, and helps the retention of oil on the bearing surface. Although a lead-tin overlay became commonly used in aircraft bearings, indium inclusions are claimed to avoid possible seizure. Other examples are cadmium alloy bearings with diffused indium and copper-lead bearings both steel-backed in the normal way. Research by the Pontiac Division of General Motors showed that as little as 0·38% indium diffused into cadmium bearing-alloys brought a marked decrease in rate of corrosion. In diffusing indium in an oven or oil bath the parts are held at 350° F., that is some degrees above the melting point of indium (311° F.), the diffusion time being shortened by increasing the temperature, but only after the diffusion has begun, otherwise surface bubbles may appear. For normal bearing treatment a thickness of 0·001 in. of lead is recommended, with indium then plated up to 4½% of the weight of lead—a very small proportion, indicating that although indium is expensive, the small amount required in plating compensates for this. It is claimed that, at the present price of indium ($7 per oz.), the metal is competitive with other finishes. Indium can be successfully plated by use of cyanide, fluoroborate, sulphate and sulfamate baths, the cyanide bath being popular because of high quality of deposit and superior throwing-power. The fluoroborate bath is more recent and has received varying reports on its value compared with the cyanide bath used so long in silver-plating. The fluoroborate solution is almost as great a hazard in use as the cyanide. Birmingham platers have favoured the sulphate bath for normal purposes.

In reviewing the rise of indium during the last few years, after nearly a century as a metal too " rare " for commercial use, a variety of other applications or poten-

(*Continued on page* 237)

The Effect of Plastic Deformation and Strain Ageing on the Transition Temperature of Mild Steel

By T. R. G. Williams, M.Sc., A.I.M. and D. H. Hughes, B.Sc. (Eng.)

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The results of an investigation using the Tipper notched tensile test as a criterion of notch ductility in assessing the effect of plastic deformation on transition temperature are at variance with the published information on investigations using notched impact tests. Plastic deformation within the range 2–10% linear strain lowers the transition temperature, and subsequent strain ageing results in partial recovery. Cottrell locking effects appear to play a relatively small rôle in the brittle behaviour of mild steel at low temperatures.

SINCE the highlighting of the brittleness of some materials at low temperatures in the catastrophic failure of Liberty ships during the Second World War, a great deal of experimental work has been carried out on this phenomenon. Nevertheless, the amount of information available on the effect of plastic deformation on the transition temperature of mild steel is rather limited, despite the practical importance of this effect, both in cold forming operations and in local plastic deformation occurring at points of high stress concentrations under load.

The following is a quotation from a review of the effect of cold work on the mechanical properties of pressure vessel steels by Lankford:[1]

> "It is generally recognised that cold working impairs the ability of ferritic steels to resist the initiation of brittle fractures. In actual practice the effects of strain ageing are superimposed on the effect of cold work. While the final toughness is of primary interest from the point of view of the suitability of the material for service, it is important to know the relative contributions of straining and of strain ageing to the impairment of toughness, if steps are to be taken to design steel of improved overall resistance to the effects of cold work."

The experimental work reported here was undertaken for two reasons :—

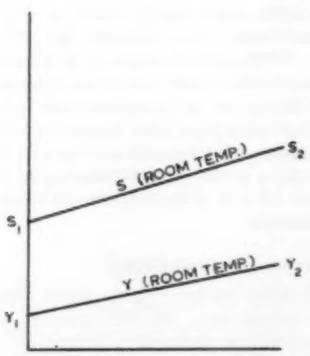
(1) To investigate the effect of plastic deformation on the transition temperature of a mild steel and to assess the relative importance of strain ageing and work hardening.

(2) To apply the Tipper notched tensile test[2] as a criterion of notch ductility, as previous experimental work had been based on the notch impact test.

Review of Literature

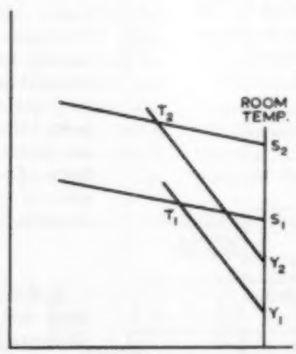
As early as 1938, Sakharov[3] investigated the differences in the transition temperatures of cold worked steels when comparatively tested in the notched and unnotched conditions. Table I shows the differences observed by the Russian investigators.

In attempting to explain these contradictory results, Sakharov applied the Ludwik–Davidenkov[4] criteria of fracture and claimed that, whereas plastic deformation increases the difference between the "technical cohesive



$(S_2 - Y_2) > (S_1 - Y_1)$

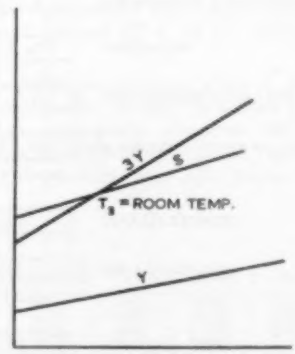
Fig. 1.—Unnotched.



$T_1 > T_2$

i.e. Plastic deformation causes a lowering of TT

Fig. 2.—Unnotched.



Y raised to 3Y in presence of sharp notch

$T_3 > T_1 > T_2$

Fig. 3.—Notched.

Fig. 1–3.—Relationship between technical cohesive stress (S) and yield stress (Y) after varying amounts of plastic flow.

TABLE I. EFFECT OF TEST PIECE NOTCH ON TRANSITION TEMPERATURE OF COLD WORKED STEELS.

	Unnotched Specimens (Davidenkov and Sakharov[3])		Notched Specimens (Kruger and Gerszonowicz[4])	
Temperature Limits of the Critical Range	No cold work	Cold work (70%)	No cold work	Cold work (70%)
Lower limit	−150° C.	−180° C.	−20° C.	−10° C.
Upper limit	−120° C.	−160° C.	+30° C.	+50° C.
Average difference ..	Lowered 35° C.		Raised 15° C.	

stress " S and the " yield stress " Y, thus lowering the transition temperature, in the presence of a sharp notch the triple tension stresses induced are more severe, and the resulting "increase" in the yield stress more than offsets the raising of the technical cohesive strength in the cold worked material (see Figs. 1, 2 and 3).

The extent of the raising of the transition temperature will depend on the notch severity and degree of cold work. Sakharov[3] supported his theory with comparative tests on small notched and unnotched cylindrical specimens subjected to varying degrees of cold work prior to testing. Fig. 4 shows the results obtained: the presence of the notch raised the yield stress, and the difference in yield between notched and unnotched samples increased with increasing cold work.

In a review of work on the effect of plastic deformation on the transition temperature of a variety of steels, published by the Welding Research Council,[5] it is shown that in general cold work raises the transition temperature of a steel, and that the magnitude of the effect is dependent upon the degree of cold work. Fig. 5 is a diagrammatic representation of the results.

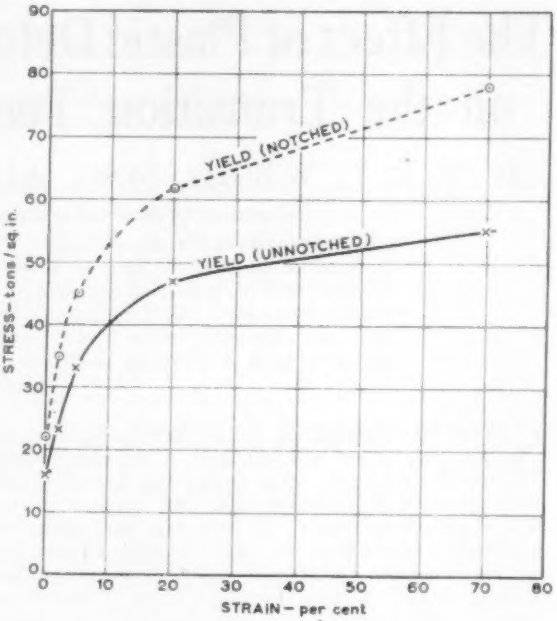


Fig. 4.—Relationship between plastic deformation and yield stress in the notched and unnotched conditions.

When the amount of prestrain is small (1–2%), the transition temperature is most affected in rimming steel and ordinary semi-killed steel. It is less affected in low carbon high-manganese semi-killed steel, and is least in killed steel. Larger strains (5–10%) raise the transition temperature of all steels appreciably. Some killed steels apparently show a slight decrease in transition temperature for small tensile strains. This phenomenon of decreasing transition temperature with varying amounts of prior deformation at room temperature has been labelled " rheotropic embrittlement," and has been investigated by several workers in the hope of obtaining a better understanding of the general problem of low temperature embrittlement in ferritic steels.

Experimental Work

Rolled steel flats, 4½ in. × ½ in. thick, were used for the production of test pieces, the percentage composition of the steel being :—

C	Si	Mn	S	P	Ni	Cr	Mo
0·17	0·05	0·76	0·031	0·034	0·1	0·05	0·05

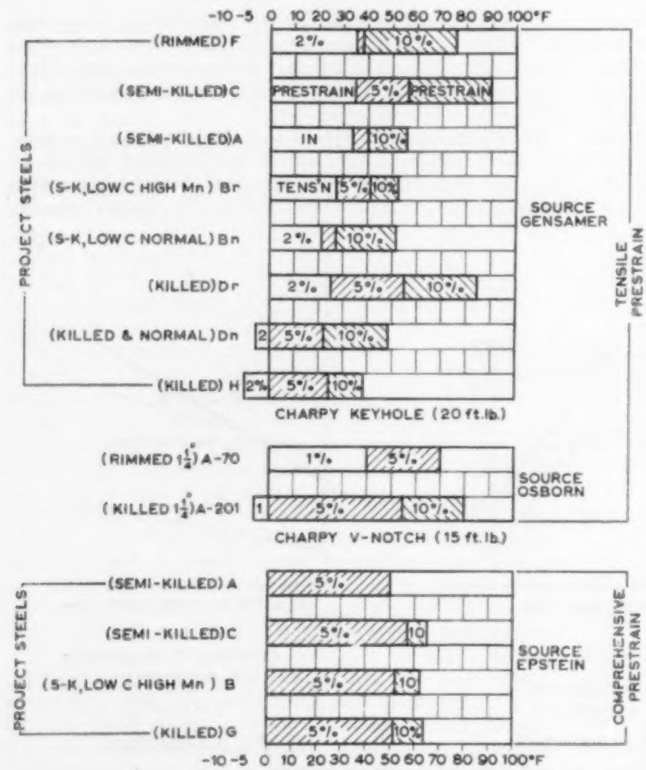


Fig. 5.—Increase in transition temperature with various amounts of prestrain. The chemical analyses of the steels concerned are given in the table on the facing page.

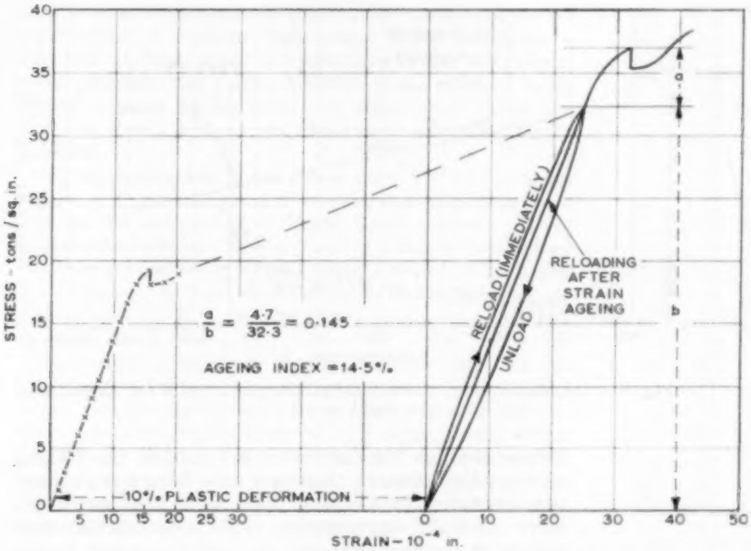


Fig. 6.—Stress-strain curve showing that reloading immediately after 10% strain followed by unloading, resulted in no discontinuous yielding; reloading after strain ageing restored discontinuous yielding.

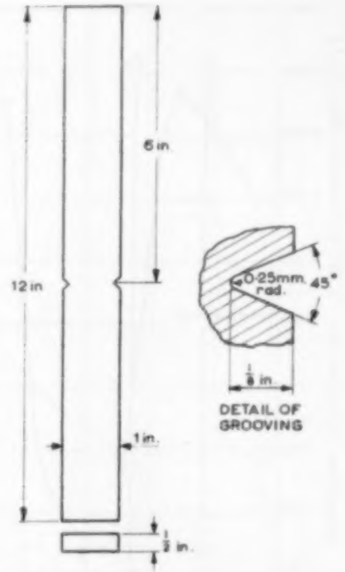


Fig. 7.—Details of the Tipper notched tensile test specimen.

An ageing index test was carried out on the steel and Fig. 6 shows the results obtained :—

Yield Point .. .. 18·4 tons/sq. in.
Ageing Index 15%

Test pieces 12 × 1 × ½ in. were cut from the flats, and after a normalising treatment of half an hour at 800° C., followed by air cooling, they were ground to size and notched as shown in Fig. 7. Control of the normalising conditions is particularly important, as shown in the work of Stout and McGready[6] (Fig. 8). A mixture of acetone and solid CO_2 (Drikold) was used for cooling the specimens to the various low temperatures at which the tensile tests were carried out.

The results obtained on a series of test pieces in the normalised condition are shown in Fig. 9. Further normalised test pieces were stretched 2%, 5%, 7% and 10%, respectively, and immediately ground to size, notched and tested, in order to obtain the transition temperature in the plastically deformed condition and before strain ageing had occurred. Strain ageing was induced in a further series by heating in boiling water for 24 hours normalised test pieces which had previously been stretched 2%, 5%, 7% and 10%, respectively. Fig. 10 shows the variation in transition temperature obtained by plastically deforming the mild steel and testing it before and after the onset of strain ageing. The curve showing the variation with testing temperature of percentage reduction of area at fracture was used for assessing the transition temperature of each test piece. In Fig. 11 the Izod impact strength of the cold worked and strain aged steel is shown.

Discussion of Results

Plastic strain greatly affected the transition temperature (T.T.) of this mild steel. At 2% strain the T.T. is −13° C. (i.e., 17° C. below that of the normalised steel) and although there is a slight raising of the T.T. to −10° C. at 5% strain, it falls sharply with increasing strain beyond this extension to −34° C. at 10% strain, i.e., 38° C. below that of the normalised structure. Strain ageing raises the T.T. by 4°, 5° and 17° C. at 2%, 5% and 10%, respectively.

The steel utilised in this experiment gave a high "ageing index," and the graph in Fig. 6 shows that plastic deformation can completely suppress discontinuous yielding of the steel, whereas strain ageing restores the discontinuous yielding and also raises the

CHEMICAL ANALYSES OF THE STEELS REFERRED TO IN FIG. 5

Steel	Thermal Treatment	C%	Mn%	P%	S%	Si%	Al%	Ni%	Cu%	Cr%	Mo%	Sn%
A	As-Rolled	0·26	0·50	0·012	0·039	0·03	0·012	0·02	0·03	0·03	0·006	0·033
Br	As-Rolled	0·18	0·73	0·008	0·030	0·07	0·015	0·05	0·07	0·03	0·006	0·012
Bn plate 1	Normalised ...	0·18	0·73	0·011	0·030	0·01	0·013	0·06	0·08	0·03	0·006	0·015
Bn plate 2			0·82			0·04	0·039	0·06	0·10	0·03	0·010	
C	As-Rolled	0·24	0·48	0·012	0·026	0·05	0·016	0·02	0·03	0·03	0·005	0·003
Dr	As-Rolled	0·22	0·55	0·013	0·024	0·21	0·020	0·16	0·22	0·12	0·022	0·023
Dm ...	Normalised ...	0·19	0·54	0·011	0·024	0·19	0·019	0·15	0·22	0·12	0·021	0·025
E	As Rolled	0·20	0·33	0·013	0·020	0·01	0·009	0·15	0·11	0·09	0·018	0·024
H	As-Rolled	0·18	0·76	0·012	0·019	0·16	0·053	0·05	0·09	0·04	0·036	0·004
N	As-Rolled	0·17	0·53	0·011	0·22	0·25	0·077	3·39	0·19	0·06	0·025	0·017
Q	1,625° F. (880° C.) W.Q. + 2 hr. 1,300° F. (700° C.)	0·22	1·13	0·011	0·030	0·05	0·033	0·05	0·13	0·03	0·036	0·018

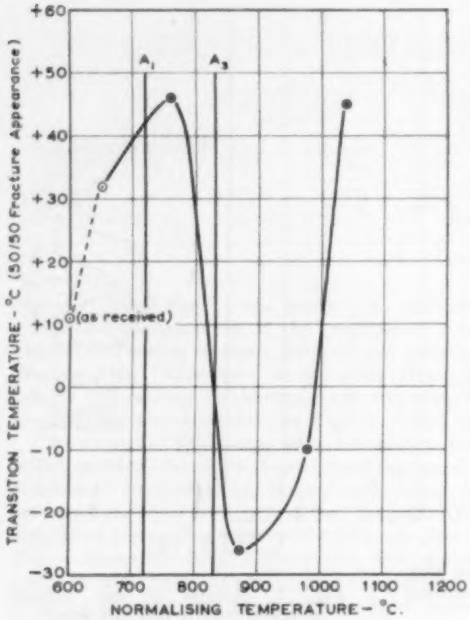


Fig. 8.—Effect of normalising temperature on the transition temperature of a ½ in. silicon-killed mild steel plate containing 0·25% C, 0·66% Mn, 0·19% Si, 0·02% P, 0·022% S, 0·04% Cr, and 0·07% Ni.

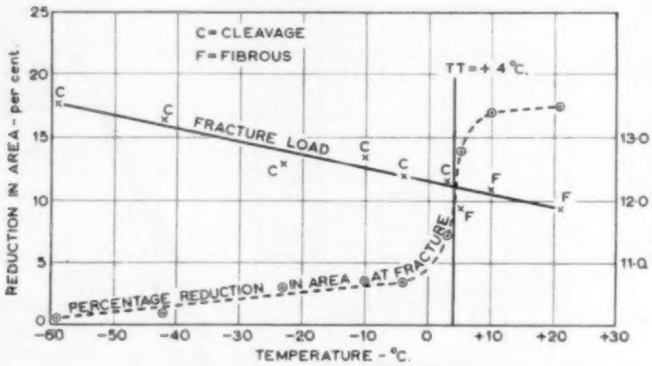
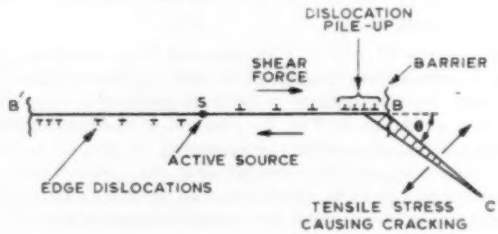


Fig. 9.—Measurement of the transition temperature of the normalised mild steel.

yield points. An explanation of these phenomena can be provided based on dislocation theory.[7] In the normalised condition the dislocations are locked in place by " atmospheres " of carbon and nitrogen atoms, and a larger force is needed to start these dislocations moving than is needed to keep them moving when they are released from the anchoring atmospheres—hence discontinuous yielding. If the load is released and then immediately reapplied the dislocations are still unlocked and no discontinuous yielding is observed, whereas if strain ageing is allowed to occur before reloading, the interstitial carbon and nitrogen atoms are given time to diffuse through the lattice to re-establish the locking effects. Furthermore, there will have been a multiplication of dislocations during the plastic flow and many more sites for precipitation will be available, thus raising the stress necessary to induce further plastic flow, and, hence, the raised values of both the upper and lower yield points of the steel. A complete explanation of these effects can therefore be provided by the dislocation theory.

The description of brittle fractures provided by dislocation theory[8] is as follows :—



As the shear stress increases, Frank-Read source S commences to operate and dislocations pile up at grain boundaries (B B′) thus causing a stress concentration. As a result of this a tensile stress is set up along the line BC at an angle θ to the slip plane. If the stresses are relieved by the operation of dislocations in neighbouring grains, then plastic flow will become general and work hardening takes place. As this proceeds, certain dislocations begin to lose their mobility due to interaction with other dislocations crossing the slip plane. It therefore becomes increasingly more difficult for the stresses to be relieved, and small embryonic cracks are formed which eventually link up giving a ductile fracture.

When Cottrell locking effects are present, however, the stress concentrations due to the pile of dislocations is not relieved and a crack will form and grow to such a length that it will propagate instantaneously. Thus the necessary condition for brittle fracture is that strong Cottrell locking effects should be present.

The experimental results, although not directly contradicting the dislocation theory model[8] of brittle fracture reveal the inadequacy of the theory in its present form in explaining the total effects observed. At 2% strain the dislocations are released from their anchoring atmospheres and the T.T., although lowered

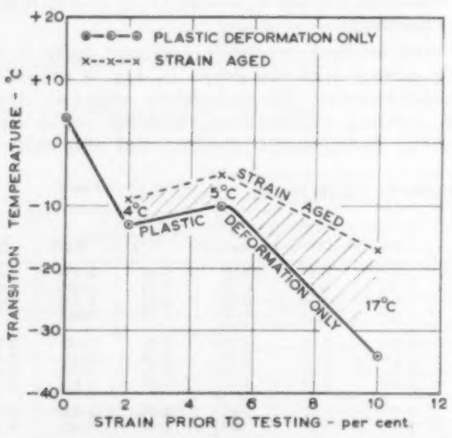


Fig. 10.—Effect of plastic strain and strain ageing on the transition temperature of mild steel.

by 17° C., is not completely eradicated. Some alternative mechanism of locking dislocations must therefore be effective at these lower temperatures in the steel structure, probably the Peierls-Nabarro stress referred to by Mott.[8] Strain ageing after 2% strain only raises the T.T. by 4° C., and so the rheotropic effect is largely retained.

By increasing the linear strain from 2% to 5% there will be a marked increase in the number of dislocations, due to the activation of Frank-Read sources. If, to explain the inflection of Fig. 7 at 5% strain, it is assumed that the proliferation of dislocations tends to raise the T.T., then a further multiplication and interaction of dislocations at 10% plastic strain produces a marked opposite effect.

Suprisingly, the strain ageing effect on the T.T. of 5% strain is only + 5° C. compared to + 4° C. at 2% strain, despite the anticipated multiplication of dislocations. At 10% strain, however, the strain ageing raises the T.T. by 17° C. These results based on the notched tensile test are at variance with the published information on the effect of plastic deformation on transition temperature measured by notched impact tests.

Conclusions

Measurements of the transition temperature of this mild steel by means of the Tipper test have shown :—

(1) Plastic deformation within the range 2–10% linear strain lowers the transition temperature below that of the steel in the normalised condition ;

(2) Strain ageing raises the transition temperature of the cold worked steel, but only partly offsets the rheotropic effects of the plastic flow.

(3) Whereas Cottrell locking effects provide a complete explanation of discontinuous yielding and strain ageing, they only appear to play a relatively small rôle in the brittle behaviour of mild steel at low temperatures.

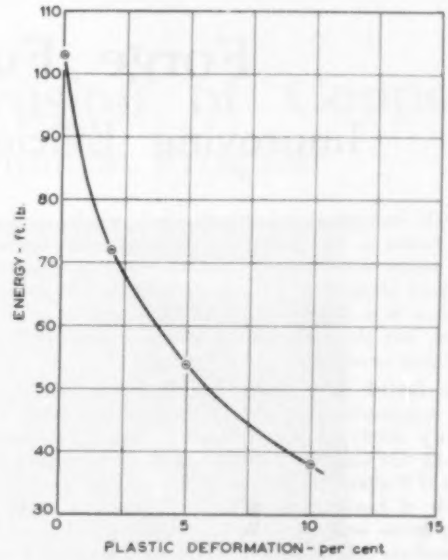


Fig. 11.—Relationship between Izod impact energy and varying amounts of plastic deformation.

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Rare Indium in the Metal Industries

Continued from page 232

tial uses may be summarised. The metal has been included as lubricant for increasing the life of deep-drawing dies, while even a fine suspension has been experimented with in lubricants. Many indium alloys have been listed among commercial forms of the element, low-melting types having been studied for fire-prevention safety-plugs, in dental and surgical metals, and in foundry patterns. While gallium seems to have declined in this field, an alloy with 24% indium is liquid at normal temperatures and may be a substitute for gallium only. A number of alloys produced by including indium in Wood's metal yield melting-points as low as 47° C. when indium reaches 19% concentration. In dental alloys attention has been given to indium, " more lustrous than silver and as untarnishable as gold," with American interests claiming " the addition of indium to dental gold solders as perhaps the biggest metallurgical improvement in a quarter century " (in dental metallurgy, that is).

Indium-rich solders have entered the electrical field with high success. Electrode connections to semi-conductors like germanium and silicon in the form of single crystal wafers have been made with indium solders, while other examples are in making solder connections to thin metal films as mirror mountings, quartz piezo-electric resonators, and other junctions. By the time the centenary of Reich and Richter's new metal is reached, rare indium will no doubt have found even wider applications in industry.

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Large Plate Stretcher Ordered

A LARGE plate-stretching machine has been ordered by James Booth Aluminium, Ltd., from Fielding & Platt, Ltd. The machine, which will be in operation early next year, will cost approximately £150,000, including installation. It will be used for flattening aluminium alloy plates, for use in shipbuilding, in the transport industry and in various other engineering applications. The maximum length of plate which can be handled on the new 144 in. wide machine, is 50 ft., and the maximum thickness is 1 in.

Forge Furnace Design

Improving Efficiency of Batch Heating

THE energy used in heating is a vitally important factor in the economics of many firms concerned solely with forging, because heating costs are a large part of the cost of the entire process. Low thermal efficiency is a characteristic of the batch-type heating process, but the performance found in practice is often lower than necessary.

The British Iron and Steel Research Association's plant engineering and energy division has made a preliminary study of forge furnace design problems by carrying out tests on a bogie-hearth forge furnace at the works of Walter Somers, Ltd. This is an oil-fired furnace, capable of heating ingots up to 65 tons in weight. It incorporates several unusual features, including high-temperature refractories, water-cooled doors and jambs, and a self-propelled bogie.

The performance of the furnace was analysed in terms of heat balances calculated for hourly intervals throughout the heating cycles, and the results indicate improvements that might be applied in general forge furnace design. A numerical method of evaluating temperature distribution in a heated ingot was verified by measurements taken in the tests; and this should lead to a technique for establishing maximum heating rates for different ingot sizes.

The factors affecting the performance of a batch-type furnace may be conveniently considered under two headings: furnace design and furnace operation.

Furnace Design

Size and Shape of Chamber

The furnace should be designed to promote high convective heat transfer to the ingot skin during the early stages of heating, while the ingot is receiving little heat by radiation from the furnace walls. In the later stages, when radiation is the major mechanism of heat transfer, provision should be made for even heating by ensuring that all faces of the ingot receive equal radiation.

Construction Materials

Because batch heating involves repeated heating and cooling of the furnace, it is essential that the furnace should have the minimum practicable heat capacity. This can be achieved by using hot-face insulating brickwork. Although the strength of this refractory is much lower than firebrick, it can be successfully used in the construction of bogie-hearth furnaces, but in fixed hearth furnaces mechanical damage is more likely. The thickness of the furnace walls should be decided by consideration of heat losses from the structure as compared with the heat stored in the structure.

Burner Design

High velocity jet burners are recommended for convective heat transfer, especially during the early stages of heating. Combined gas and oil burners can be used, and will give good convective heat transfer from high velocity gas flames in the early stages, and radiant heat from highly emissive oil flames in the later stages.

Waste Heat Recovery

To avoid large loss of heat in the waste gas it is necessary to use some form of waste heat recovery unit. This must have a low heat capacity so that it may efficiently use the variable quantities of waste heat leaving the furnace chamber. From this point of view, a recuperative system is preferable to a regenerative one.

Furnace Operation

Heating Cycles and Soaking Times

The thermal efficiency of a furnace is influenced by the heating rates and soaking times employed. Taking into consideration fuel costs, capital costs and labour costs per ton of throughput, the heating cycle should be kept as short as possible. Numerical analysis of an ingot's internal temperature distribution should lead to a technique for establishing maximum heating rates; and the soaking times needed for close uniformity of temperature can also be accurately estimated. So if the characteristic heat-transfer coefficient to temperature curve can be found for a furnace, it will be possible to predict the maximum permissible rate of rise of furnace temperature for any particular size and type of ingot being heated.

Furnace Loading

There will be a furnace loading which will produce maximum thermal efficiency. If the furnace is underloaded, a smaller proportion of heat will be taken up by the steel and thermal efficiency will be low. If the ingot is too large for the furnace, so that its head protrudes through a bricked-up doorway, heat losses from the chamber will be increased considerably. There is, then, need for careful planning in every forge shop. The furnace sizes should be carefully chosen in relation to the expected range of ingot sizes.

Furnace Control and Instrumentation

Instrumentation can greatly improve the operation of a furnace. Temperature controllers limit the amount of fuel wasted during the heating and soaking periods and prevent damage to the ingot skin by overheating. If necessary, programme controllers may be used to raise the temperature at predetermined rates. To guide the furnace operator, temperatures at various points inside the furnace should be continuously recorded.

The quantity of excess air passing through the chamber affects the waste gas losses and, consequently, the heating efficiency. A furnace pressure controller will limit the amount of excess air drawn in. This is particularly important where a large ingot with a protruding head is being heated.

A furnace pressure controller is of little use, however, unless the fuel/air ratio at the burners is also rigidly

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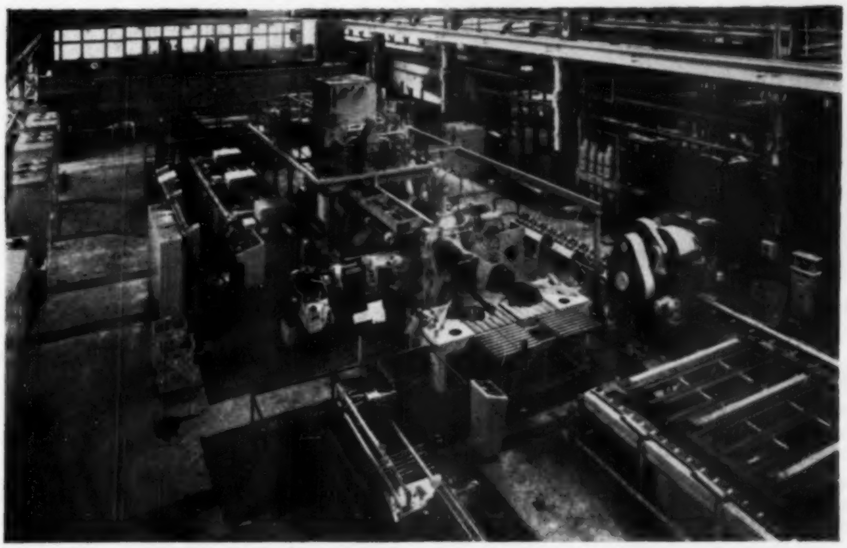
Mechanisation in Extrusion of Copper

1,700 ton Press Installation at Froghall



General view of the installation with the coilers in position at the exit side of the press.

FOR almost two hundred years, modernisation of the plant of Thomas Bolton and Sons, Ltd., has been going on, for it was in 1783 that the firm was first founded in Birmingham by Richard Bolton, described as " of Dudley, Worcester, merchant and manufacturer." In 1825 Thomas Bolton, son of Richard, built a works in Broad Street, Birmingham, where in the 1840's " brass and copper wire, rolled metals, locomotive engine and other tubing " were manufactured. Activity continued on the site until 1912, when the works was moved to Froghall, near Stoke-on-Trent, in Staffordshire. Today the company has factories in Froghall and Oakamoor, Staffordshire and in Widnes and St. Helens, Lancashire.

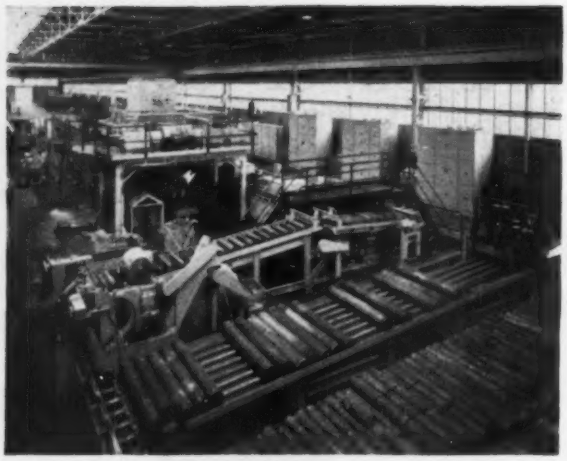
The seal was set on the latest stage in the modernisation when, on 28th April, Sir William McFadzean, chairman and managing director of British Insulated Callenders' Cables, Ltd., officially opened the mechanised extrusion plant at the Froghall works. The plant, one of the most up-to-date and mechanised in the country, was designed and supplied by The Loewy Engineering Co., Ltd., of Bournemouth. It comprises a 1,700 ton oil-hydraulic extrusion press, with three Loewy Magnethermic mains frequency induction heaters, and completely mechanised gear for the supply of billets to the press and for the removal of the extruded product.

Handling and Heating Billets

The billet handling gear on the incoming side of the press was designed and built by Loewy Engineering Co., Ltd. Cast billets are delivered by fork lift truck on to three inclined ramps, down which they roll to control gates beside the roller conveyor which carries them to the saw. All billet movements, from the ramps to the magazine which feeds the Magnethermic heaters, are under push-button operation from the sawyer's operating position. Sawing is done on a Russell 28 in. circular saw specially adapted to fit into the equipment, and any length can be cut between 10 in. and 27 in. Sequence switches ensure that the cut billets are fed to whichever heater is ready to receive them.

Three Loewy Magnethermic mains frequency induction units are available to heat the billets to extrusion temperature. Each has a rating of 500 kVA. and is provided with Honeywell Brown temperature controllers, calibrated up to 1,000° C. Two sets of coils are available to suit billets of normal diameters of 6 in. and 8 in., respectively. Secondary tappings at approximately ¾ in. intervals are available to allow for differing lengths of billet, but the five most commonly used are taken to a heavy selector switch and can be chosen at will. The desired billet temperatures are set on the adjacent heater control panels, and at 850° C. the total capacity of the heaters is about 6 tons of copper per hour, equivalent to 57 billets per hour at 6 in. diameter $\times$ 27 in. long or 31 billets per hour at 8 in. diameter $\times$ 27 in. long. The air cylinders which control billet selection and movement can be operated by hand for testing purposes, but are normally under automatic control from the main operating desk.

Power is supplied to the heaters at 3·3 kV. (3-phase), and power factor correction is taken care of by three B.I.C.C. capacitors, each of 1,000 kVA. rating capacity, a five-step switch allowing correction to be adjusted according to the power input to the coils. Cooling



Fork truck delivering billets to the saw-feeding ramp.

water requirements amount to some 40 gal./min. per coil plus auxiliaries, and cooling of the water from 65° C. to 30° C. is effected by 4,800 gal./hr. Visco cooler.

Extrusion

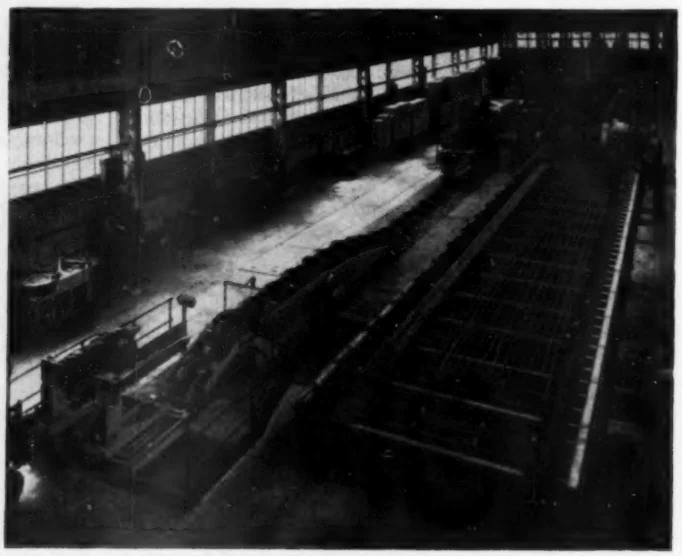
The main feature of the plant is, of course, the Loewy 1,700 ton horizontal extrusion press, which is of a special off-set three-column design and incorporates a rotating die-holder enabling dies to be brought to an outer station for dressing or changing without any hold-up of production. Driven by a Vickers hydraulic pump, a turning cycle can be completed in 6 seconds. To allow for the utmost flexibility in the production of the widest range of products, the press is provided with a 60 ton hydraulic die face shear and a 36 ton hydraulic vertical shear.

The total weight of the press and auxiliaries is approximately 225 tons, the heaviest single piece—the main ram assembly—weighing 31 tons. The main ram has a diameter of 32½ in. and a stroke of 71 in. Twelve pre-set extrusion rates are provided to ensure that any size or type of product can be extruded under the most suitable conditions, the maximum ram speed being about 1 in./sec. The working fluid is 1,500 gal. of Shell Tellus 27 hydraulic oil and the working pressure of 4,500 lb./sq. in. is provided by ten Towler five-throw high speed oil pumps driven by two 250 h.p. 3·3 kV. Laurence Scott motors, which together with the electrically-controlled oil hydraulic valves are mounted on a platform above the press. A sealing force of 200 tons is provided by two sustaining pumps: the stripping force is 297 tons.

Fully automatic operation of all movements, from the acceptance of a cold billet for heating to the final elimination of the discard and re-closing of the press, is provided in two stages. The first stage consists of discharging a hot billet from the appropriate heater, conveying it to a position in line with the container bore, placing a pressure disc behind it and reloading the heater coil with a cold billet. This cycle is completed by pressing a button on the main control desk when the appropriate signal light shows that a billet is up to temperature. A second button initiates the extrusion cycle proper, which carries through all stages of extrusion, cutting off, and discard ejection, ending only when the press is ready for the next hot billet.

Manual control is, of course, available for testing purposes. This, like the choice of which shear is to be included in the automatic cycle, is controlled by a selector switch on the desk. The provision of so much automatic sequence switching not only reduces idle time to a minimum, thus catering for a high production rate, but also makes for safety, as no movement can start until the previous one has been satisfactorily concluded. A guide to the completeness of the automatic features provided is given by the fact that the press control panels contain over a thousand switch

The Magnethermic induction heaters.



The cooling conveyors for coils (left) and straight lengths (right).

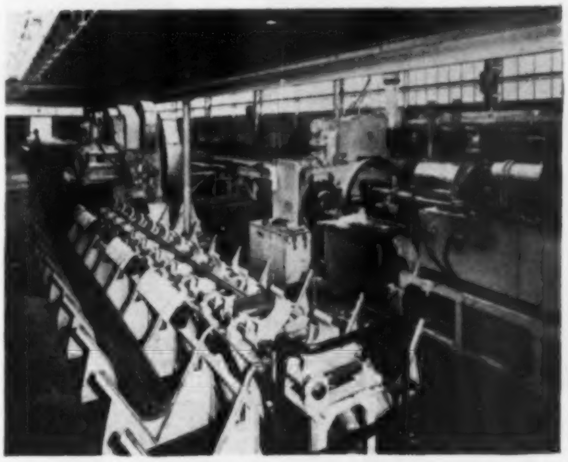
contacts and that eighteen miles of cable were required in the installation.

Handling the Press Output

Completely mechanised handling gear is provided for both straight lengths and coils. The run-out system for straight products was built by the Marco Conveyor and Engineering Co., Ltd., and consists of a roller track, which can be driven at any speed required to match the extrusion rate, and a cross transfer and cooling conveyor capable of handling lengths of up to 75 ft. A dead plate is provided between the run-out rollers and the transfer conveyor, so that initial cooling can take place while the material is fully supported throughout its length. A part of the dead plate is strengthened to allow for hammer straightening of large sections where this is appropriate.

After cooling, the material is delivered to the shear line. For normal cutting to length, the shear makes single strokes when a pedal is depressed, but a selector switch makes continuous cutting available when required, with a maximum rate of 24 strokes per minute. An inching position provides for blade changing and cutting clearance adjustment. Lengths for cutting are fed through the shear to a stop by a powered roller conveyor under the control of the shearer. On the discharge side of the shear a roller table receives the cut lengths. This incorporates throw-off arms allowing the lengths to be stacked in reception racks on either side of the shear line.

Vertical axis twin coilers of special design with a 15 h.p. hydraulic variable speed drive have been installed to handle either rod (maximum diameter 1¼ in.) or strip (maximum width 6 in.). When dealing with rod, the centrifugal principle is used and the rod is simply poured into the coiler basket, but for strip coiling a special torque-limiting device is fitted which enables pancake coils of controlled tightness to be wound with an inside diameter of 20 in. and an outside diameter of 36 in. In both cases the coiled material is lifted above the pegs by a rising bottom plate and pushed across to a slat conveyor for cooling. After cooling, they are mechanically lifted on to a boom which, when full, is picked up by Stacatruc and the coils transferred to the storage area. The mechanised coil handling equipment was built by Moxey, Ltd., of West Bromwich.



Sheared lengths being stacked. Note the die-rotating gear to the right of the centre.

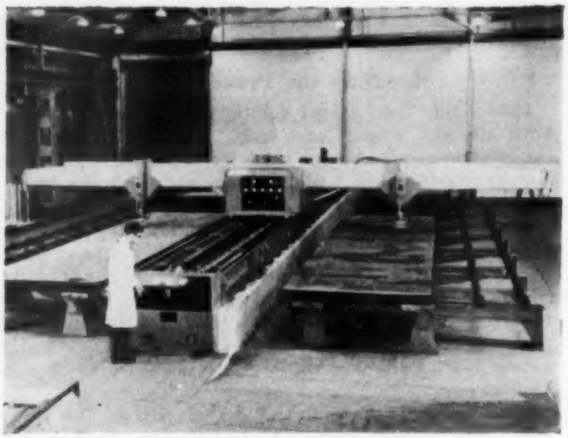
Power Supplies

Power to the press equipment is supplied from a sub-station at the end of the press building. Here the incoming 11 kV. supply is fed to four 1,000 kVA. transformers; three of these provide a secondary voltage of 3·3 kV. for the main pump motors and for the Magnethermic heaters, and the fourth provides power at 415 V. for the many auxiliary motors and other equipment. The whole of the sub-station equipment—which includes an air circuit breaker with a rupturing capacity of 25 mVA. at 400 V.; an oil circuit breaker with a rupturing capacity of 100 MVA. at 3·3 kV.; and an oil circuit breaker with a rupturing capacity of 250 MVA. at 11 kV.—was supplied by the English Electric Co., Ltd.

Chromium Plating Jaguar Trim

Jaguar Cars, Ltd., have recently put into full production at Coventry a nickel and chromium plating installation with a capacity sufficient for both current and foreseeable future requirements for body trim. Ever-increasing production requirements led to the decision to carry out this installation, together with the desire for improving plating quality and reducing plating costs. The plant, which was designed, constructed and installed by the Electro-Chemical Engineering Co., Ltd., of Woking, Surrey, consists of two return-type fully automatic plating machines (seen here on right) and a manually controlled straight-through line.

Computer-Controlled Oxygen Cutting Machine Installed in Shipyard



THE world's first fully-automatic machine for cutting ships' plate to shape has been installed in the Wallsend-on-Tyne shipyard of Swan, Hunter & Wigham Richardson, Ltd. Developed by British Oxygen, the computer-controlled oxy-acetylene flame cutting machine is a highly advanced machine which provides an important step towards improving production methods in shipyards. It incorporates the well-proven Ferranti machine control system, using a magnetic tape which contains movement orders obtained from an electronic computer. The new machine cuts out the need for templates or battens for marking-off purposes, and it gives a high-quality accurately-cut edge, irrespective of the shape of the cut: with present methods this is only possible on straight plates. It enables operational procedures such as plate sub-division and nesting for cutting to be done as an office procedure. The system is sufficiently flexible for " one-off " or multiple runs to be made with almost equal economy.

The computer-controlled cutter works considerably faster and with far greater accuracy than conventional cutting machines. It can, for instance, cut two plates at once, each up to 40 ft. long × 12 ft. wide × 3 in. thick. Although the first machines have been designed specifically for shipyard use, the development will find applications in other fields where profiled plate is widely used—e.g. in marine and structural engineering, locomotive building, and the atomic energy programme.

Method of Operation

Cutting plates to shape (or profiling) is a major and important part of ship construction. Up to the present time, the first stage has been to produce small scale plans of the ship's lines. From these, full scale lines are laid off in the mould loft. Wooden patterns, or templates, are then made from the " lofted " lines and these are used, in conjunction with the steelwork drawings, to mark out the required shapes on the steel. All is then ready for cutting. Most, if not all, of this preliminary work will be eliminated by the new computer-controlled cutter. In addition, a hitherto unachievable standard of accuracy in machine cutting is now possible.

In the new system, information on the cuts to be made is taken direct from the steelwork drawings, the table of dimensions or, in some cases, the lofted lines, and put on a punched paper tape. At the computer centre, the paper tape is fed into a computer which works out the movements of the machine's cutting heads. The orders for these movements are recorded on a magnetic tape together with the necessary commands for starting the cutting. At the shipyard, the magnetic tape is played back on the machine control console. To indicate the direction to be taken by the cutting heads, the console sends a recorded train of impulses from the tape to the longitudinal and transverse motion controls of the cutting machine. The same magnetic tape controls all other required functions such as gas control, automatic flame ignition and nozzle height control. The flame and the cut are continuously monitored so that in the event of failure, the machine stops immediately.

E.S.C. Order for A.E.I.

ENGLISH STEEL CORPORATION, LTD., has placed an order worth nearly £1 million with the heavy plant division of Associated Electrical Industries, Ltd., for electrical equipment for four rolling mills which are to be installed at English Steel Corporation's new Tinsley Park Works, Sheffield. The equipment will include two 3,500 h.p., D.C., motors for the twin drive of a 42 in. blooming and slabbing mill which will be supplied by Davy and United Engineering Co., Ltd., and The Brightside Foundry & Engineering Co., Ltd., acting together as a consortium. The two motors are to be installed with the upper motor nearer the mill than the other—this is the " top-forward " arrangement which was pioneered in the United Kingdom by A.E.I. Two 32 in. billet mills, which will also be supplied by the consortium, will be equipped with A.E.I. motors—one of 4,000 h.p. and the other of 5,000 h.p. The bar mills, ordered from The Brightside Foundry & Engineering Co., Ltd., will comprise a reversing roughing mill driven by a 2,000 h.p. motor; an intermediate mill driven by a 1,000 h.p. motor; and a continuous mill driven by five 450 h.p. motors and two 350 h.p. motors. As well as the main motors, A.E.I. will supply and instal steel-tank mercury-arc converters which will provide power for the D.C. motors; motor and rectifier ventilation equipment; all the D.C. circuit breakers; open-type slate motor control panels; motor supervisory cubicles; electronic controls; and magnetic amplifiers.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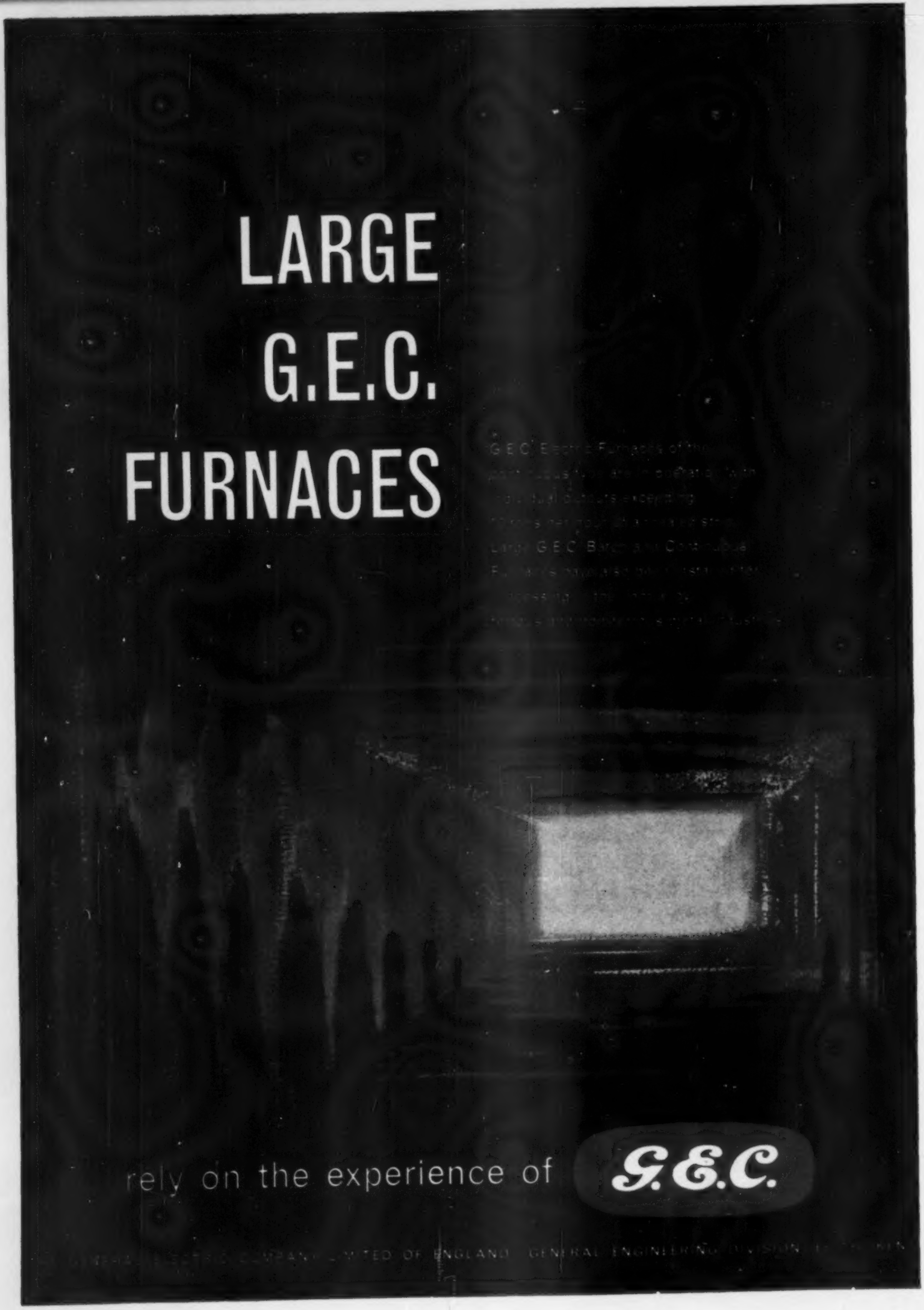

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NEWS AND ANNOUNCEMENTS

AEI-Birlec Dryer and Gas Plant Department

DUE to the somewhat related activities of atmosphere generators and adsorption drying equipment, since furnace atmosphere gases are sometimes dried or otherwise purified by adsorption methods, AEI-Birlec, Ltd., have co-ordinated the sales, design, research and service activities applicable to both gas generators and dryers.

As makers of controlled-atmosphere furnaces for bright annealing, clean hardening, case hardening, sintering, etc., AEI-Birlec, Ltd., have experience extending over thirty years of designing and building atmosphere generators. A wide range of standard units has been developed in this period, including exothermic, endothermic and nitrogen generators covering almost all heat treatment processes. During the same period, the company has also developed an extensive business in adsorption equipment, primarily for removing water vapour from air and other gases. In this case, also, standardisation has progressively rationalised designs and " packaged " units are now supplied for the majority of process requirements, including low-humidity air conditioning.

The dryer and gas plant department of AEI-Birlec is well equipped to handle a variety of special gas-treatment requirements outside the range of the standard units. Many important installations of this kind have been made in nuclear energy, aeronautical research, oil refining and other diverse fields, representing the growing importance of this specialised work.

Visit by E.F.T.A. Journalists

THIRTEEN journalists representing leading newspapers from member countries of the European Free Trade Association visited this country recently as the guests of the British Iron and Steel Federation. The group not only visited steel works, but also had the opportunity of seeing other important industries and meeting industrialists, Members of Parliament and some of their journalistic colleagues in this country. The tour ended in London on 1st May with a dinner given by the president of the British Iron and Steel Federation, Mr. C. R. Wheeler, C.B.E. A spokesman for the Federation said that the visit had been arranged because the British Steel Industry is anxious to encourage the closest possible exchanges between member countries of the Association.

Quality Control Symposium

THE enthusiastic reception accorded the quality control symposium organised by Elliott Brothers (London), Ltd., and held at Caxton Hall, London, in September last, has encouraged the company to arrange a similar meeting for this year. The symposium will be held on Tuesday, 13th and Wednesday, 14th June and an attendant exhibition will feature a range of some twenty-five types of analytical instruments, technicians being in attendance to explain their operation. The five papers will be presented for discussion on the Tuesday evening and Wednesday morning and the organisers have been fortunate in obtaining the active co-operation of Mr. L. Farey of the Mobil Oil Co., and of Mr. J. Mawson of I.C.I. (Billingham), who have both consented to read papers on the subject of analysis type instrumentation in the process industries. In addition, Mr. Hallikainen, president of the American company of that name, is making a special visit to deliver a paper covering some aspects of the American scene in this field. Mr. D. Fraade of Consolidated Electrodynamics Corporation will discuss applications of continuous process stream analysers in the United States and finally Mr. T. R. Wills of Elliott Brothers will speak on trends in process analysis.

Progress at Durgapur

WITH the satisfactory testing of No.3 blast furnace, now ready for operation, the entire iron making facilities at the Durgapur Steelworks, West Bengal, India, have been completed. Like its predecessors, it is rated to produce 1,250 tons of iron per day and this output has already been frequently exceeded on No. 1 and No. 2 furnaces. The iron-making plant will produce hot metal for the melting shop and iron for foundry uses. The three blast furnaces are fed by a comprehensive coke, iron ore and limestone handling system feeding into bunkers on the furnace high line. All raw materials are carried from the bedding plant by a conveyor system, although provision has also been made for feeding the furnaces by rail-borne raw materials.

In the melting shop too, with the completion of the testing of the final unit—a 100 ton open hearth furnace—all the steelmaking facilities have now been installed. The work has been completed well ahead of schedule; three furnaces went into production last year and the dates for commissioning the others remain to be fixed. The melting shop consists of seven 200-ton open hearth furnaces and the 100 ton unit referred to above, which has been designed for the specific purpose of producing special steels for the manufacture of wheel sets for the Indian Railways. In full production, the plant will produce a million tons of ingot steel a year.

Both iron and steelmaking plants were designed and built by member companies of ISCON—the Indian Steelworks Construction Co., Ltd.—the consortium of British Companies responsible for the construction of the Durgapur works, Britain's largest ever single export order—worth £120 million.

The Morgan Crucible Group

As foreshadowed in last summer's announcement, The Morgan Crucible Co., Ltd., ceased to trade on 3rd April and became a holding company. From that date, its responsibilities for production, trading, research and development have been assumed by the following five new wholly owned subsidiaries:—

Morganite Carbon, Ltd., Battersea, S.W.11: carbon products (electrical), carbon products (mechanical), and sintered bearings (" Reservoil ")

Morganite Crucible, Ltd., Norton, Worcester:

crucibles (Super), crucibles ("Suprex"), and furnaces and foundry accessories

Morganite Electroheat, Ltd., Wandsworth, S.W.18 : furnace elements ("Crusilite")

Morganite Research and Development, Ltd., Battersea, S.W.11 : research and development

Morganite Exports, Ltd., Battersea, S.W.11 : export

Other United Kingdom subsidiaries in The Morgan Crucible Group (of which The Morgan Crucible Co., Ltd., is the holding company) are :

Morgan Refractories, Ltd.

Morganite Resistors, Ltd.

Ship Carbon Company of Great Britain, Ltd.

Graphite Products, Ltd.

Morgan Components, Ltd.

Morgan-Mintex, Ltd.

C.D.A. 'At Home'

On the evening of the 5th April, 1961, the chairman and council of the Copper Development Association entertained a large gathering of representatives of the various bodies concerned with the organisation and activities of the Association. Amongst those present on this occasion were council members and representatives of the Association's member companies, members of the British Non-Ferrous Metals Federation and its development committee, and of the copper and nickel industry committee of the British Non-Ferrous Metals Research Association, together with members of their staffs. Cocktails and light refreshments were served in the Association's spacious showroom at 55, South Audley Street, London W.1, where members of the C.D.A. staff also assisted in entertaining the eighty or so guests who attended.

"Fair Oriana"

Just as the Elizabethen madrigal sang the praises of "Fair Oriana," so the latest United Steel film tells the proud story of her twentieth century namesake, and all who worked in her creation. T.S.S. *Oriana* (42,000 tons) is the largest passenger vessel to be built in England—the Cunard *Queens* were of course built on the Clyde—at the Barrow yards of Vickers-Armstrongs (Shipbuilders), Ltd.

The "Oriana" in the fitting-out basin.

As well as being fitted with stabilisers, the *Oriana* has manoeuvring jets which enable the captain to give the unusual order : "Full speed—sideways !"

The opening shots, taken from the air, show the vessel on her sea trials, the scene then switching to the plate and section mills of Appleby-Frodingham Steel Co., at Scunthorpe, which contributed large tonnages of steel to the vessel's construction. Steel strip plays a large part in the manufacture of tubes, pipes and ventilation ducts, and sequences showing the hot rolling of this material in Steel, Peech & Tozer's Brinsworth mill are featured in the film. Following some spectacular shots of the launching of the vessel by H.R.H. Princess Alexandra on November 3rd, 1959, two types of metal forming are depicted; first is seen the forging of propeller shafts, and later the industrial designer Robert Welch is shown at work on the prototypes of the stainless steel cutlery which he designed specially for use on this liner.

For the maiden voyage, the film switches dramatically from colour to black-and-white so that this memorable occasion can be seen on the ship's own closed circuit television. In the gathering dusk of a dull December afternoon, *Oriana* drops the pilot and sails off on the long voyage to Australia—a voyage appreciably shortened by the existence of this "symphony of steel in power and grace."

The film is photographed in Eastmancolor and is available in 16 mm. and 35 mm. sizes, and may be borrowed on application to The Public Relations Officer, The United Steel Cos., Ltd., The Mount, Broomhill, Sheffield, 10.

European Promotional Work On Lead

A series of exploratory meetings was held in London on the 5th/6th April on European promotional work on lead. The meetings were attended by heads of the lead development associations of France, Germany, Great Britain and Italy and a representative from the Belgian lead industry. The work of each association was discussed and an exchange of views took place on the main uses of lead in each country. Possible new applications, such as sound attenuation, were explored, and it was agreed that samples of publications and booklets would be exchanged. Before the meetings ended plans were made for further co-operation and it was agreed, at the invitation of Istituto Italiano del Piombo e dello Zinco, to hold a further meeting in Rome next September to which representatives from other European countries would be invited. The meeting noted with satisfaction that the consumption of lead had steadily increased in recent years.

Conference on Inspection and Non-Destructive Testing

A national conference is to be held at Oxford in September of this year to discuss the function of management in relation to inspection, the economics of inspection and non-destructive testing, and the recruitment, education and training of inspection staffs. The conference is being planned at the request of the Joint Committee on Materials and their Testing and the British National Committee for Non-Destructive Testing. It is being organised jointly by the Institution of Engineering Inspection and the Society of Non-Destructive Examina-

tion. The speakers invited are all closely associated with their subjects and have wide experience in the fields concerned. Sessions will be arranged to allow ample time for discussion.

In view of the wide interest already expressed by industry, learned societies and the teaching profession, residential accommodation at Queen's College and New College, Oxford, has been reserved over the period 5th to 8th September, 1961. The total cost including conference fee, accommodation and all meals in college will be £9 10 0 per delegate. Those who wish to have further information should write to the Oxford Conference Secretariat, The Institution of Engineering Inspection, 616 Grand Buildings, Trafalgar Square, London W.C.2. This will involve no obligation but will ensure that full details will be sent as soon as they are available.

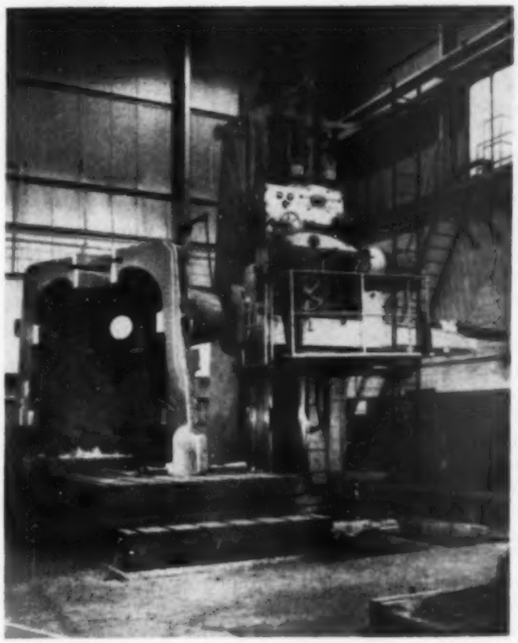
Personal News

MR. L. G. W. PALETHORPE, who has been associated with Wild-Barfield Electric Furnaces, Ltd., and G.W.B. Furnaces, Ltd., for the past twelve years, has recently taken up an appointment with Salem-Brosius (England), Ltd., as manager of their heat treatment division. This appointment coincides with the policy of the Salem organisation to expand their activities in the engineering heat treatment field in order to cover a wider variety of furnaces and heat treatment processes.

MR. A. BAILEY has been elected a vice-president and MR. J. O. HITCHCOCK an assistant vice-president of The International Nickel Co. of Canada, Ltd., effective 10th April, 1961. Mr. Bailey remains chairman and chief officer of The International Nickel Co. (Mond), Ltd., and of Henry Wiggin & Co., Ltd. Mr. Hitchcock remains managing director of The International Nickel Co. (Mond), Ltd., and deputy chairman of Henry Wiggin & Co., Ltd. He will also continue as second chief officer of both companies.

SEVERAL new appointments are announced in the commercial department of Appleby-Frodingham Steel Co., a branch of The United Steel Cos., Ltd. MR. R. G. SMITH is appointed assistant commercial manager, MR. C. R. BENNETT is appointed sales manager (heavy products), and MR. I. E. STEWART becomes sales manager (light products). In addition, MR. C. A. GRIFFIN is appointed raw materials officer and MR. I. W. PETTINGER will succeed MR. L. E JACKSON as head of quotation section (heavy products) on the latter's retirement at the end of June.

CASTROL, LTD., announce that, on 1st January 1962, four assistant managing directors will be appointed to handle the growing expansion of the group's worldwide interests and further developments envisaged in the future. They are MR. J. A. V. WATSON, O.B.E., MR. L. G. PACKHAM, MR. C. E. R. MILLIDGE and MR. A. A. BARR, all of whom are directors of the parent company. The new assistant managing directors will have equal responsibility to the deputy chairman and managing director, MR L. M. BROADWAY, and the board. These changes will follow the retirement, at the end of the year, of MR. W. F. LIST, assistant managing director since 1951. Mr. List who has served the company for over 50 years will remain on the Castrol board, where his long experience will be invaluable.



Rough machining a turbine cylinder casting at the Penistone works of the foundries division of David Brown Industries, Ltd. This is one of four castings, weighing on average 10 tons each, recently supplied to the turbine-generator division of Associated Electrical Industries, Ltd., for the high pressure cylinders of 300 MW sets to be installed in the C.E.G.B. station at West Thurrock, Essex. The sets will operate at initial steam conditions of 2,300 p.s.i.g. and 1,050° F., with reheat to 1,050° F.

BRITISH INSULATED CALLENDER'S CABLES, LTD., announce that MR. J. VARLEY and MR. G. H. PARR, refinery manager and sales manager, respectively, of British Copper Refiners, Ltd., of Prescot, have been appointed directors of that company.

ON March 31st, 1961, MR. E. STOTT, the export sales manager of Turner Brothers Asbestos Co., Ltd., retired after 42 years' service with the company. The new export sales manager is MR. J. C. T. FELL, who until recently, was the export sales manager of Ferodo, Ltd. —a sister company of Turner's in the Turner & Newall organisation.

MR. E. C. GILL, president of The Canada Life Assurance Co., has been elected a member of the advisory committee of The International Nickel Co. of Canada, Ltd.

MR. G. COOKE, for the past few years publicity director of the Solartron Electronic group, now part of the Firth Cleveland group, has been appointed group publicity director to head a new Firth Cleveland division which will co-ordinate and control advertising and public relations for the group and all its member-companies. He will remain a director of Solartron.

THE DELTA GROUP have appointed MR. A. F. THOMAS and MR. D. J. W. DOLTON to the boards of Sperryn & Co., Ltd., the Birmingham brassfounders and finishers, and gas, water and electrical lighting fittings manufacturers, and C. H. Edwards, Ltd., the plumbers' brassfoundry manufacturers at Bilston, Staffordshire. Mr. Thomas is

an assistant managing director of The Delta Metal Co., Ltd., whilst Mr. Dolton is personal assistant to the directors and assistant secretary

Mr. H. A. Latham has been appointed a director of Sanderson Brothers & Newbould, Ltd. Mr. Latham first joined the company's steel department in 1938, and after demobilisation in 1946 he returned to the company and was appointed forge and rolling mills superintendent in 1953.

Mr. H. W. G. Hignett and Mr. J. M. Dhavernas have been appointed directors of The International Nickel Company (Mond), Ltd. Mr Hignett remains managing director of Henry Wiggin & Co., Ltd. Mr. Dhavernas is located in Paris and has been closely concerned for many years with nickel markets on the Continent.

Dr. E. S. Hedges, director of the International Tin Research Council, recently returned from a business tour of the United States, in the course of which he met representatives of tin consuming industries in America, and discussed with them those aspects of the work of the Tin Research Institute in which they were particularly concerned. Dr. Hedges' tour included visits to Los Angeles, New Orleans, Baton Rouge, Cincinnati and New York. He also visited Columbus, Ohio, for conferences at the American office of the Tin Research Institute.

The Board of G.K.N. Steel Co., Ltd., announce the appointment of Mr. C. F. Pagnamenta, O.B.E., as a director. Mr. Pagnamenta remains as secretary of the company. The company also announces the following appointments as local directors : Mr. A. T. Harris, chief engineer of Brymbo Steel Works; to Guest Keen Iron & Steel Works board : Mr. T. Dennison, group development officer.

Mr. J. A. Croft, deputy chairman and managing director of Crofts Engineers (Holdings), Ltd., has been appointed chairman of that company and its principal operating subsidiary companies, including Crofts (Engineers), Ltd., and Carter Gears, Ltd., in succession to his father, the late Sir Arthur Croft.

Mr. E. T. Card has been appointed a director of Electrothermal Engineering, Ltd.

The Steel Company of Wales, Ltd., has announced that Mr. Godfrey Walker has been appointed public relations officer, and that in future he will be based at the London office—Margam House, St. James' Square. In his new position he will have the additional duties of advising the chairman and the sales controller on matters affecting prestige and commercial advertising. Mr. Walker joined the company in 1947 as information officer at Port Talbot and has been responsible for the press relations and publicity in the steel, tinplate and Newport divisions throughout the whole period of the company's post war development schemes. Mr. Wendell Leyshon the assistant information officer has been appointed information officer and will take over the duties formerly carried out at Port Talbot by Mr. Walker.

Mr. A. G. M. Grezo has been appointed sales manager of Workington Iron and Steel Co., a branch of The United Steel Cos., Ltd., he will be responsible to the commercial manager, Mr. J. Laird, for the sales of all Workington products.

Alcan Industries, Ltd., announce the election of two new directors to their board, Mr. A. A. Bruneau and Mr. R. J. Moyse. Mr. Moyse, who was appointed chief financial officer and treasurer of the company last year, joined the Aluminum, Ltd., organisation in 1951, serving with Aluminum Securities, Montreal, and latterly as secretary-treasurer of the Indian Aluminum Co., Ltd. Mr. Bruneau joined Alcan Industries (then Northern Aluminium) last year as secretary. His career with Aluminium, Ltd., which began in 1949 with the Aluminum Company of Canada, included an earlier period with Northern Aluminium, and he was latterly with Aluminium Secretariat, Montreal.

Sir Ellis Hunter retired at the end of March from all executive appointments in the Dorman Long group, including the joint managing directorship of Dorman Long (Steel), Ltd. He will continue as chairman of Dorman, Long & Co., Ltd., and its principal subsidiary companies. Mr. E. T. Judge has been appointed deputy chairman of Dorman, Long & Co., Ltd., and managing director of Dorman Long (Steel), Ltd., of which he was previously joint managing director.

Mr. St. John de Elstub, C.B.E., has been appointed chairman of the metals division of Imperial Chemical Industries, Ltd., in succession to Mr. M. J. S. Clapham, who has joined the company's main board as an overseas director. Mr. Elstub is chairman of Amal, Ltd., an I.C.I. subsidiary, and a director of Yorkshire Imperial Metals, Ltd., the tube producing company operated jointly by I.C.I. and Yorkshire Copper Works (Holdings), Ltd. Dr. W. H. G. Lake, O.B.E., has been appointed joint managing director (technical) of the metals division in succession to Mr. St. John Elstub. Dr. Lake was appointed assistant research manager of I.C.I. metals division in 1952 and a director of the metals division in 1957.

Mr. H. Smith, who has been chairman of I.C.I. general chemicals division for the past two years, has been appointed a director of I.C.I. with effect from 23rd March. He will take over as technical director from Dr. R. Beeching on 1st June, when Dr. Beeching becomes chairman of the new British Transport Board.

Mr. M. J. S. Clapham, who has been chairman of I.C.I. metals division since 1st January, 1960, has been aapointed a director of I.C.I. He is to be an overseas director *vice* Dr. J. S. Gourlay, who is to be group A director (responsible for alkali and general chemicals divisions). Mr. Clapham is a director of Pyrotenax, Ltd., Yorkshire Imperial Metals, Ltd., and Imperial Aluminium Co., Ltd.

Dr. E. Gregory and Mr. B. B. Green, directors of Edgar Allen & Co., Ltd., have relinquished their full-time executive positions as chief metallurgist and general sales manager, respectively, but they remain in office as non-executive directors and the company will be able to avail itself of their services in a representative or consultative capacity as may be desirable from time to time.

Mr. J. E. C. Bailey, C.B.E., chairman and managing director of Baird & Tatlock (London), Ltd., Hopkin & Williams, Ltd., and W. B. Nicolson (Scientific Instruments), Ltd., recently visited America and Canada to continue discussions with American associates on the further developments in the Analmatic range of process control instruments. During his stay, Mr. Bailey attended the annual meeting of the Scientific Apparatus Manufacturers' Association at White Sulphur Springs.

RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Aluminium Stud Welding

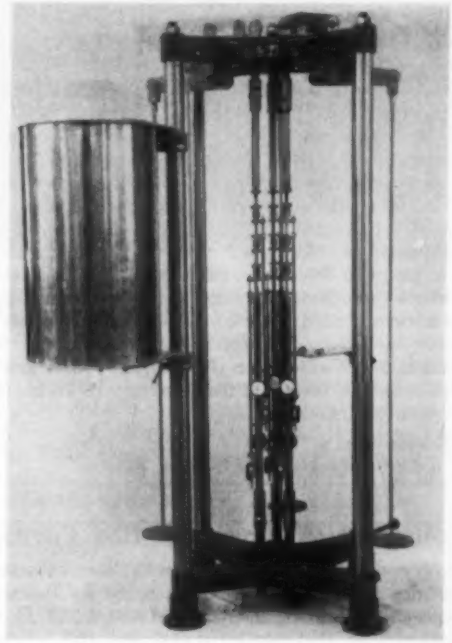
A NEW technique has been devised for stud welding to aluminium alloys which has the effect of minimising porosity and atmospheric contamination. Recent tests carried out by Crompton Parkinson (Stud Welding), Ltd., on the cast metal produced by an aluminium stud weld showed that this suffered from impurities derived partly from the film of oxide and partly from the residue of a drawing lubricant on the stud, and further aggravated by atmospheric contamination during the weld cycle. The film on the stud was removed by skimming it in a lathe and the contamination was dealt with by excluding the atmosphere and substituting argon gas in its place, the first time that argon gas has been used in stud welding. The inert gas is introduced and contained in the weld zone through a brass shroud which goes around the stud and ferrule in the weld position. A valve attachment at the base eliminates gas wastage by releasing the argon flow only when the handtool is in position. The use of the argon attachment has been found to be completely successful for the complete range of aluminium alloy studs up to and including $\frac{7}{16}$ in. diameter.

On $\frac{1}{2}$ in. studs the complete prevention of porosity set a greater problem, and to overcome the slight reduction in strength caused by microscopic porosity, the weld base area was in effect increased. This was done by making use of the metal displaced when the stud is returned to the molten pool. Investigations showed that fusion did not occur between the displaced metal and the stud sides because the stud periphery was too cold. This led to the development of a preheat arc unit, the function of which is to heat the stud to the required temperature immediately before the weld is made. In practice, it is found that a current of approximately 70A. and a duration of 3 seconds give the desired conditions for a $\frac{1}{2}$ in. alloy stud. With the exception of the argon attachment and the preheat arc unit, the rest of the equipment is completely standard.

Crompton Parkinson (Stud Welding), Ltd., Crompton House, Aldwych, London, W.C.2.

Multi-Specimen Creep Machine

ORIGINALLY developed and built for the Royal Aircraft Establishment, Farnborough, W. H. Mayes and Son (Windsor), Ltd., are now marketing a medium accuracy creep or stress-rupture machine capable of testing simultaneously in tension, three strings of four specimens in series. Each string is loaded independantly by a double lever system having knife edges throughout, and provision is made in the base to restore the lever system to horizontal by gears and a gear lever quadrant to take up extension. The capacity of the machine is two tons per string. Dial gauge extensometers can be fitted to all twelve specimens for creep testing and removed for stress-rupture work. Extensometer attachment is made by collets for ridge type specimens, although collets can be supplied for use with plain specimens.



Specimen heating is by a five-zone furnace, each zone being independantly fed, and the furnace is hinged on a pillar for ease of loading the specimen and extensometer assemblies. The temperature is controlled by a saturable reactor controller, with power rheostats for gradient control, built into a small compact free standing cabinet. It will be noted that the lever system and weight pans are on three sides of the machine only, leaving one side free from any obstruction.

W. H. Mayes and Son (Windsor), Ltd., Vansittart Estate, Arthur Road, Windsor, Berks.

Nuclear Detection

WITH the development of nuclear devices and their common usage in industry, there has developed a need for a simple but reliable Geiger counter at an economic price. Photoelectronics (M.O.M.), Ltd., have therefore included this in their development programme and have now produced the Amatron portable radiation monitor to an approved Harwell design. The unit is ideally suited for teaching, demonstrating and showing the presence of beta/gamma emitting elements. Low energy beta radiation can be monitored by changing the G.M. tube. Visual and audible means are provided for indicating contamination by use of a large neon and a $2\frac{1}{2}$ in. loudspeaker. Provision is also made for using an external meter (0–500 μA. D.C.) or connecting up to an amplified loudspeaker system. The G.M. probe is separate and attached to the main unit by 6 ft. of co-axial cable. The monitor is either battery or mains operated.

Radiation from an external source ionises the gas in the G.M. tube which gives out a pulse large enough to trigger the neon circuit. The neon in turn supplies a pulse which gives an audible signal in the loudspeaker for each count. When the meter is inserted into the circuit by means of the jack plug, the current through the neon circuit is maintained and since this is proportional to count rate, the scale of the meter can be suitably calibrated.

The probe consists of a Geiger Muller tube fitted into an octal valve base and contained in a protective sheath. Also contained in the sheath is a condenser and resistor fitted in series with the co-axial cable. To facilitate replacement, the tube and components are fitted to a base piece which can be completely withdrawn from the sheath. The probe is normally stored in a clip fixed on the side of the main case.

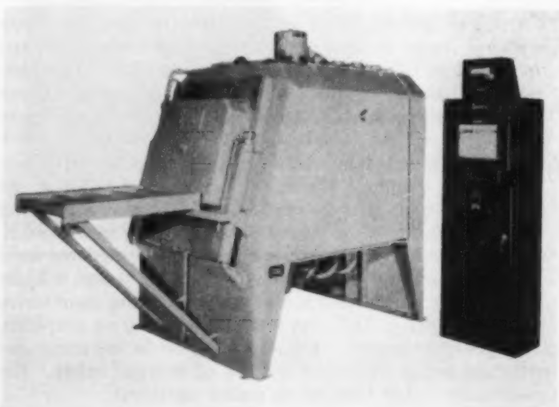
Contained in the main unit is the neon indicator which projects from the front by approximately ½ in. in order to give good all-round visibility and is protected with a metal guard; a loudspeaker, with speaker transformer; a jack socket for meter connection; battery or mains unit (whichever is required); and associated components. Conversion from battery to mains is easily and quickly carried out.

Photoelectronics (M.O.M.), Ltd., Oldfields Trading Estate, Oldfields Road, Sutton, Surrey.

Controlled Atmosphere Box Furnaces

The manufacture of a complete line of controlled atmosphere box furnaces is announced by Ipsen Industries, Inc. Operating temperatures of 1,300° C. can be maintained in the smaller units, and the larger units will be capable of temperatures exceeding 1,200° C. These furnaces are available as gas fired, oil fired, or electrically heated units, and excellent temperature uniformity is maintained because the charge is heated by 100% forced convection. The charging door and door plate of the tightly sealed units are one-piece normalised Meehanite castings which are rigid and resist warping. Sliding surfaces are machined flat and the door is raised by dual airdraulic cylinders.

The high temperatures quoted are made possible by the absence of metal parts inside the furnace, the protected atmosphere being circulated by a ceramic fan. Heating is effected by means of Ipsen super alloyed ceramic heating tubes that are impervious to high-carbon and high-hydrogen atmospheres as well as being resistant to extreme changes in either heating or cooling. An exclusive 100% premix ceramic burner fires upward to assure complete combustion within the heating portion of the tube. The ceramic burner is said to have extremely long life since it is not affected by high temperature operation, or exposure to contaminating-type atmospheres. Coupled with the use of Ipsen super alloyed ceramic flame busters, this feature increases heating efficiency, resulting in more heat being transferred to the work from a given amount of fuel.



Ipsen box furnaces can be manually charged, or they can be used with mechanised loaders and unloaders for production line heat treating operations. The units are expected to find uses in the tool room, and for other applications where controlled atmosphere heating is desired, but where it is unnecessary to hold work under controlled atmospheres following the heating operation.

Ipsen Industries, Inc., 53 Victoria Road, Surbiton, Surrey.

Combustion Safeguard Relay

An improved Protectoglo combustion safeguard relay using the flame rectification principle, is announced by Honeywell Controls, Ltd. In one relay, it is claimed, are embodied all the most advanced techniques in this field. These include: a choice of all accepted sensors for all applications without modification; fully plug-in chassis and purge timer; automatic lock-out on unsuccessful ignition start; and a self-checking circuit to prevent start-up if any component becomes faulty, or if the sensor already detects flame. The Protectoglo relay is designed for use with sensors of the flame-electrode, photocell unit, infra-red, or ultra-violet types, and two different kinds of sensor can work-in simultaneously to the same Protectoglo.

For gas flames, a flame-electrode rectifier is normally used, the electrode being inserted in the flame which forms part of the circuit. The flame acts as a rectifier if interposed between two electrodes of unequal area; the burner, or ground electrode when used, generally has an area of contact many times that of the flame electrode. For oil flames a photocell rectifier is generally sighted onto the flame. The photocell is a natural rectifier; when light from the flame strikes it, the photocell produces rectified current from the applied alternating current. For gas or oil or combined flames, an infra-red sensor in the form of a lead sulphide cell responds to pulsating infra-red radiations, and unidirectional current is produced by means of an adaptor circuit.

Another, more unusual, sensor is the ultra-violet detector, which cannot be fooled by incandescent brick work, since it responds only to the ultra-violet light present in the flame. Typical uses of this detector include dual fuel installations, high intensity gas flames, exothermic gas generators, and other difficult applications.

When flame is present, rectified current is fed to the Protectoglo relay into one grid of a double-triode electronic tube. The triodes are connected so that the output current will energise the control relay. On flame failure no rectified current can be produced, the tube output current drops to zero and the control relays "drop out."

The self-checking safe-start circuit in the relay includes a safety switch and a manual reset button. If a fault is detected during start-up and the safety switch goes into the safety position, the system cannot be started until the unsafe condition is corrected and the manual reset button actuated.

When it is required to prevent any attempt to start the burner until expiration of a measured time interval, during which the combustion space may be thoroughly purged of any accumulation of unburned fuel, a purge timer is supplied. This timer is located in the upper right hand corner of the relay. The purge timer is fully adjustable from 2 to 15 minutes or, alternatively, 4 to 30 minutes. At the end of the purge timing period, an external signal light indicates that the burner may be started.

Honeywell Controls, Ltd., Greenford, Middlesex.

Foundry Pattern Letters

The successful introduction of polythene pattern letters for the foundry trade by A.E.I. Plastics (Aldridge), Ltd., is now followed by a new range of sharp faced pattern letters for the small sizes (below ½ in.) which have the advantage of producing an improved impression on all types of castings. In common with the range of larger pattern letters, the new type are only half the price of equivalent metal characters.

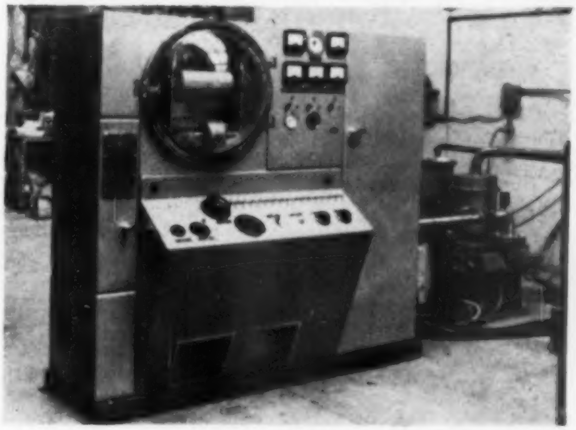
Polythene characters are extremely resilient—direct hammer blows cause only momentary distortion and the most rigorous hand or machine ramming is withstood without burring. In addition, polythene has good " non-stick " properties and the useful characteristics associated with lead. It is pliable and can be easily moulded to any contour ; it can be pinned or glued to a pattern without difficulty, and it is unaffected by water. The characters are normally supplied in light grey to contrast with the conventional red, yellow and black used for pattern identification.

A.E.I. Plastics (Aldridge), Ltd., Redhouse Industrial Estate, Aldridge, Staffs.

Vacuum Metallising

The latest version of the V.M.D. 12 in. continuous vacuum metalliser has many advantages and improvements over earlier models. The machine is designed as a self-contained unit ready for operation after connecting up the mechanical vacuum pump and power, air and water services. Most materials in roll form can be processed at speeds up to 1,200 ft./min. although for thick coatings a speed of 800 ft./min. is preferred. Materials which have been successfully treated include vegetable parchment, G.I.P., friction glazed paper, glassine, Cellophane, cellulose acetate, polyester and P.V.C. films, pliofilm and most coated packaging materials. The ability to coat base material without previously drying has been extended to certain grades of vegetable parchment, and nearly all known plastic films can be metallised immediately as received from the supplier. This feature is of great value as it reduces the cost of operation and there is no appreciable change in the quality of the material being handled.

The material is mounted in the machine in the form of rolls 12 in. diameter by 12 in. wide. The vacuum chamber is then closed and pumped down over a period of about two minutes. The web passes over a heated continuous evaporation source and is then rewound in



the main chamber of the machine. Air is admitted in less than a minute after coating, the finished roll is removed and the cycle is repeated. A production rate of more than 25,000 linear ft./hr. of material can be readily attained. This newest equipment has been designed specifically with the needs of the capacitor market in mind. If one single operation plastic film or capacitor issue can be metallised and provided with a blank margin and then slit and rewound on to bobbins suitable for the direct winding of capacitors.

Although metallised film has until recently been used only for specialised capacitors, this new process is said to be economic as compared with the use of aluminium foil for the manufacture of a wide range of larger capacitors for general use in the electrical and electronics industries. Film resistances of the order of 1½ ohm/sq. are readily achieved, and rewinding and marginating are carried out to tolerances of better than $\pm 0{\cdot}2$mm.

Vacuum Metallurgical Developments Ltd., Shelford, Cambridge.

Larger Hollow Bored Bars

Larger hole diameters and increased bar lengths are now offered by the hollow boring department of Keeton, Sons & Co., Ltd. Keetona hollow bored bars are now available with finished machined bores to a tolerance of ± 0.003 in. in diameters from ¾ in. to 12 in. Honed finished bars to a tolerance of ± 0.001 in. are available in diameters from 2 to 12 in. The outside diameter is rough-turned to ensure straightness and concentricity. The maximum length, which is cut to suit customers' requirements, is now 18 ft. The standard range of materials includes commercial quality mild steel (u.t.s. 28/32 tons/sq. in.) or 0.34/0.45% carbon steel (u.t.s. 37/42 tons/sq. in.), but alloy steel and non-ferrous, deep-bored bars can also be supplied to customers' orders. Keetons are also able to supply finished components to fine limits, profiled on the outside diameter, screwed, and with stepped bores as specified by the customer.

Apart from the precision finished bored bars, the Keetona range of products also includes rough-finished hollow bored bars in mild or 37/42 ton carbon steel to tolerances of $\pm 1/32$ in., with concentricity tolerance of $\pm 1/16$ in. in sizes from 1½ in. O.D. (⅛–⅜ in. bore) to 10½ in. O.D. (⅜–6½ in. bore). Hollow bored forgings up to 28 in. outside diameter and 5 tons solid weight can

be supplied; on lengths up to 10 ft. these can be bored to a blank end or stepped with varying diameters.

Keeton, Sons & Co., Ltd., Greenland Road, Sheffield 9.

Mild Steel Welding Electrode

ASSOCIATED ELECTRICAL INDUSTRIES LTD., has introduced a new Class E.217 mild steel welding electrode, the Gazelle. The new electrode represents an addition to the range formerly known as Metrovick electrodes (with names Sylvick, Castivick, etc.). The Gazelle has been developed to obtain smooth and speedy welding; features include high travel speeds, longer runs per electrode than with standard Class 2 electrodes, and a combination of characteristics that ensure high quality welds with maximum ease of operation. Of the non iron-powder, contact type, the Gazelle is capable of satisfactory operation over very wide current ranges; for example, the current range for a 4-gauge is 190–350A. Operation is similar to that of iron-powder contact type electrodes, with an added advantage of negligible spatter, and deslagging properties are said to be unequalled in the Class 2 range. Gazelle electrodes are approved by Lloyds and the Ministry of Transport.

A.E.I. (Manchester), Ltd., Trafford Park, Manchester, 17

Flame Failure Control

THE photoelectronic flame failure control Type GFF has been designed to provide a safety system for oil, gas or pulverised fuel burners. It operates on the modulation of the flame irrespective of colour or background radiation and should the flame go out then the unit will cut off the supply of fuel immediately. This new unit produced by Photoelectronics (M.O.M.), Ltd., with its universal application to all types of fuel and its built-in safety circuits, provides the answer to many combustion problems.

In addition to operating as an on/off device in conjunction with a solenoid valve, the equipment can be fitted with an automatic sequence unit to provide a fully automatic control system for the burners. This sequence unit consists of a synchronous motor with cam system and switches to provide a sequence of operations for lighting-up, with the over-riding control of the photocell to ensure complete safety. The equipment is complete with indicating lights to show the condition of operation and the photocell is contained in a cast aluminium tube for easy mounting.

Photoelectronics (M.O.M.), Ltd., Oldfields Trading Estate, Oldfields Road, Sutton, Surrey.

Automatic Lubricant Injector

THE FOUNDRY & METALLURGICAL CO., LTD., has introduced an automatic lubricant injector which solves the problem of plunger lubrication in pressure die-casting machines where the use of heavy lubes is generally considered essential. The injector is a two stage unit capable of dispensing heavy graphite-bearing compounds. The first stage draws the lubricant from a supply tank and pumps it to the second stage at a pressure of about 200 lb./sq. in. From the second stage the lubricant is pumped at pressures up to 1500 lb./sq. in. and in quantities from 0.045 cu. in. to less than 0.005 cu. in. The quantity is controlled with steel distance pieces which limit the intake of lubricant. The pumping system has a fully scavenging action which ensures that the right measure is delivered every time and prevents build-up within the system.

On a pressure die-casting machine an injection is made after every cast to ensure consistent but not excessive lubrication. The efficiency of the lubrication introduces an economy in lube and reduces wear on both plunger and sleeve. The unit, which can be fitted to existing machines, operates from a compressed air supply of 60 to 150 lb./sq. in. and can be controlled by an air pilot, a solenoid or a mechanical roller valve.

Foundry & Metallurgical Equipment Co., Ltd., Netherby, Queens Road, Weybridge, Surrey.

Ferro Alloy Briquettes for Iron Foundries

FERRO ALLOY BRIQUETTES are now marketed by the alloys division of Union Carbide, Ltd., in a new shape and with improved packaging. At the same time the price is reduced as a result of lower production costs, concessions on contracts for raw materials, and economies in packaging. The new production plant—believed to be the first of its type to be installed in Europe—is fully automatic, and embodies certain patented features providing uniform size, weight, texture and quality in the briquettes.

The 1 lb. briquette has been discontinued, but the 2 lb. briquettes have a notch at the centre to facilitate even splitting. Each briquette carries the same amount of metal as formerly and is identified by the same colour code. The new briquettes will be despatched in bundles with a weight of 60 lb. for silicon and zirconium-silicon, 56 lb. for manganese and chromium, and 52 lb. for silicon-manganese. The bundles are packed with corrugated paper, continuously labelled according to the colour code, and banded with a metal strap. A further contribution to the price reduction is provided by concentrating ferro silicon manufacture on the 45–50% grade widely used in the ironfounding industry.

Union Carbide, Ltd., Alloys Division, 8 Grafton Street, London W.1

Basin Tilter Furnace

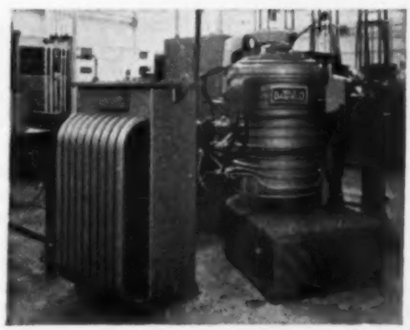
THE Morgan Crucible Co., Ltd., has now extended its range of crucible furnaces by producing one of 1,300 lb. aluminium capacity. It is designed on similar lines to the two very successful smaller furnaces known as the Basin Tilter Types BT.380 and BT.500. The range of furnaces is designed to provide simple and flexible melting units embodying all the features stipulated by the aluminium die casting industry,* viz: high melting rate—1,300 lb./hr.; low fuel costs—19s./ton of metal; hydraulic lip axis pouring—with variable control; low metal loss—under 1%; and low crucible costs—8s./ton of metal. The BT.1300, considering its large capacity, is a very compact unit; the low platform and large diameter crucible facilitate the charging of bulky scrap. Although particularly suitable as a bulk melter for the die casting foundry supplying metal for bale-out furnaces, it is equally successful when used on its own.

The Morgan Crucible Co., Ltd., Battersea Church Road, Battersea, London, S.W.11.

*The two smaller furnaces are also being extensively used for the melting of copper base alloys.

Vacuum Brazing at S.E.R.L. Harlow

The advantages of vacuum brazing include extremely clean work and joints of great strength, free from pinholes and made without fluxes.
That is why the Services Electronics Research Laboratories (Microwave Electronics Division) at Harlow are using the Wild-Barfield internal element type vacuum furnace shown for brazing special assemblies.
Remember that the experience of Wild-Barfield covers the design and manufacture of all types and sizes of vacuum furnaces.



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W.B. 101

CURRENT LITERATURE

Book Notice

REACTORS OF THE WORLD

Second series. 13 cutaway drawings, 8 in full colour, reprinted from *Nuclear Engineering*. Published by Temple Press, Ltd., Bowling Green Lane, London, E.C.1. 17s. 6d. net.

THE greater opportunity for the examination of alternatives and for the introduction of new or experimental systems, which has resulted from the deceleration in the power reactor construction programmes of nearly all countries, makes even more difficult the task of keeping abreast of developments which face the design engineer, executive and component manufacturer. From time to time the journal *Nuclear Engineering* publishes cutaway drawings of new reactors, together with details of the type, purpose, location and construction. The present volume is a collection of thirteen such drawings which were originally published in the period April 1958 to October 1960. They include some reactors which are being constructed or have already been completed in overseas countries, their inclusion being necessary to produce a balanced selection in what is essentially an international sphere of activity.

In these second series, greater use has been made of colour in order to lend clarity to the flow pattern of the reactor system or to highlight particular design features, and wherever possible the virtues of colour coding have been combined with those of realism and artistic appeal. It was felt when the first series was published that the opportunity of presenting so many 'firsts' would not occur again, but little repetition is apparent in the present volume and the fact that many designs of fundamental importance have yet to be presented suggests that a third series is likely in the not too distant future.

Trade Publications

JOHNSON MATTHEY & CO., LTD., have produced an entirely new version of their publication 1302, "Electrical Contacts." This booklet is intended to help designers of electrical and electronic equipment not only to select contact materials that will perform a given duty with the greatest efficiency and economy but also to determine optimum contact dimensions and operating force. Under the headings Electrical Conditions and Mechanical Conditions are discussed the general considerations affecting selection of material and design of contacts. The rest of the booklet is devoted to description of the properties and availability of JMC contact materials with detailed information and data on the different types of contacts in the JMC standard contact ranges. Also included are sections on electrodeposited contact surfaces, on light duty slip rings and brushes, and on contact springs.

A NEW leaflet entitled "Rocol Anti-Scuffing Products" has been produced by Rocol, Ltd., of Swillington, nr. Leeds, which very concisely gives the products and uses of the four main molybdenum disulphide lubricants on which the company's trade is based. They are anti-scuffing oil, anti-scuffing paste, anti-scuffing spray and anti-scuffing powder. Short descriptions of the products are given, together with a schedule of prices. The back of the pamphlet gives examples of reports from a wide range of industries detailing improvements achieved by the use of these products.

MOST companies make a good deal of effort to reach their potential customers by means of advertising, mailing schemes, etc., but it sometimes happens that customers and potential customers wish to reach the company. In such cases, a leaflet such as that recently produced by Incandescent Heat Co., Ltd., entitled "How to Reach Us," giving details of routes by rail, bus and private transport, is an excellent help and can save much time and frustration.

As usual, *Foseco Foundry Practice* No. 145 features a report on an investigation by the service personnel of Foundry Services, Ltd., this time dealing with blowholes and inclusions in a grey iron cast valve component. In another article, suggestions are made for avoiding hard spots in aluminium castings, whilst a third article describes a method of casting thrust collars on to shafts or spindles.

NOTWITHSTANDING the new furnace developments and the treatment of newer and more exotic materials, the more standard types of equipment still play a major role in industry, and in the March issue of *The Wild-Barfield Heat Treatment Journal*, a description is given of an installation of four batch furnaces for the annealing of brass strip. Other articles in this issue are concerned with the vacuum brazing of difficult alloys; an induction heating installation for the heat treatment of ring gear components; and the operation of the Wild-Barfield N.R.C. Model 912 vacuum gas analyser in determining the gas content of metals.

THE abstracts comprising the February issue of *The Nickel Bulletin* provide an apt illustration of the wide range of industries and applications in which nickel plays an important role. The seventeen abstracts in the electrodeposition section, which reflect, *inter alia*, the considerable amount of work which is being carried out to improve the corrosion-resistance conferred by nickel/chromium coatings, are followed by items covering literature on non-ferrous alloys, nickel-iron alloys (including a new glass-to-metal-sealing alloy) and the production, heat-treatment and welding of nickel-containing cast irons. The properties and fabrication of high-strength constructional steels are receiving considerable attention, and due reference is made in the *Bulletin* to thirteen recent papers of interest in this respect. The section concerned with heat- and corrosion-resisting materials is, as usual, the largest of the issue, the literature abstracted ranging in content from the mechanical properties and fabrication of heat-resisting stainless steels and high-temperature alloys to materials suitable for handling liquid gases, studies of passivity in stainless steels, and the resistance of nickel-containing alloys and steels to specific corrosive media.

IN the December 1960 issue of *Engelhard Industries Technical Bulletin*, obtainable from the Baker Platinum Division, 52 High Holborn, London, W.C.1., there appears an article on the purification of coke oven gases with

platinum metals catalysts, which discusses the removal of NO, NO_2, C_2H_2, COS and Diolefins. Of interest to the analyst is an item describing a spectrographic method for the quantitative determination of low concentration impurities in high-purity fine silver.

"HARD SURFACING ALUMINIUM CYLINDERS" is the title of an article featured in *Metco News*, Vol. 9 No. 7, which discusses flame spraying steel on light metals to provide a hard bearing surface, thus replacing steel cylinder liners in aluminium engine blocks. Copies can be obtained from Metallizing Equipment Co., Ltd., Chobham, near Woking, Surrey.

MACHINE TOOLS for steelworks application continue to find an important place in the *Craven Machine Tool Gazette*. In the March-April 1961 issue, there is a description of a 65 in. heavy roll grinding machine which has been installed in an important British steelworks. Also featured in this issue are a 48 in. wormwheel hobbing machine, a single head plano-milling machine, a portable milling machine and a 70/98 in. centres break lathe.

A SLICE of precious metals history appears in the April 1961 issue of *Platinum Metals Review*, the Johnson, Matthey publication, under the title "The First Experiments on Platinum." An account is given of the work of William Brownrigg, the publication of the results of which, in the *Philosophical Transactions* of the Royal Society, led to those other investigations which finally established the nature and characteristics of the metal. In another section of the review the constitution and properties of the rhodium-platinum alloys are discussed and other articles deal with the application of the platinum metals in the production of light duty electrical contacts, glass fibres and nitric acid.

WHAT is described as a revolutionary cold-heat process for hardening gear tooth profiles is described in a new publication by Delapena & Son Ltd., entitled "The Cold-Heat Submerged Induction Hardening Process." This process is said to differ from other methods of induction gear hardening in that a patented intensifier suitable for operation at radio frequencies is used, and in that the heating is carried out with the gear submerged in the quench medium. The intensifier is a special type of inductor with a copper conducting path for the R.F. current and a laminated iron core to concentrate the magnetic field into the area to be heated. It is claimed that by this process distortion is kept to a minimum; scaling is completely obviated; tooth strength is high; and the power requirements are low, so that an R.F. generator of comparatively small output can be used for any size of gear. Topics discussed by the question-and-answer method include comparisons with other methods of gear hardening, types of work that can be handled, distortion, hardness and strength, suitable steels, installation of equipment, intensifiers, and the process and its operation. Finally a complete description and specification of the machine is given.

No. 17—the latest issue of *Inco-Mond Magazine*—has increased its page size to the continental pattern 21 × 27 cm. ($8\frac{1}{4} \times 10\frac{5}{8}$ in.), and also adopted a modern easy-to-read layout which combines an attractive appearance with an economical usage of available space. This page size is already in use for the foreign-language editions of the magazine which appear in French, German and Italian and are widely circulated on the Continent and elsewhere. The post-war era of nickel shortage has finally come to an end and industry is today making extensive and growing use of nickel-containing materials. It is to provide a more comprehensive coverage of the part that nickel plays in industry, commerce, research and the home that The International Nickel Co. (Mond), Ltd., has introduced a new and larger version of its well known journal. This new issue of *Inco-Mond Magazine* includes many articles on the diverse uses of nickel-containing materials, including: heat resisting steel pipes in modern blast furnace tuyères; nickel gunmetal caps in the overhead electrification of railways; nickel-chromium-molybdenum steel as used for the sphere of the Bathyscaphe which reached the ocean's deepest point—seven miles down; a report on the testing of 9% nickel steel as a suitable material for very low temperature service ("cryogenics"); a new chromium-nickel casting alloy to resist fuel-oil ash corrosion in boilers and superheaters; retractable lifeboat davits on T.S.S. *Oriana* made of nickel-aluminium bronze; and 18/8 stainless steel in Swissair mobile staircase driving mechanisms.

RECENT developments in open hearth steelmaking techniques, including the use of liquid fuels, oxygen enrichment of the combustion air and the use of oxygen in the bath, have provided the operator with a means of speeding up the rate of steel production which, in turn, has made it possible to operate at temperatures far in excess of those used in traditional firing conditions. The use of these higher temperatures, in some cases over 1,700° C., has necessitated the use of basic bricks in the roof, and a new publication of General Refractories, Ltd., provides a guide to the selection and application of the appropriate grades of basic brick in open hearth furnace roofs. Details are given of four grades of brick (two metal-cased) and various types of sprung, semi-suspended and fully-suspended roofs are discussed.

THE April-May issue of *The Bonderizer* is devoted to the G.K.N. group of companies. Following the introductory note on the group and its history, there are a number of features dealing with a few of the eight or more companies in the group which use processes developed by the metal finishing division of the Pyrene Co. Among the products concerned in these articles are motor car wheels, office furniture and equipment, and automatic vending machines. Reference is also made to the use of Bonderizing in cold working steel.

WE have received from London Fan & Motor Co., Ltd., two new publications. The first is concerned with Breezamatic dual fan units, designed for use where continuous ventilation is vital and equipped with automatic control for starting stand-by fan in the case of failure of the running ventilator. The other leaflet deals with Breeza cast iron blowers whose applications include dust extraction, fume exhaustion and the provision of blowing air for forge furnaces.

A RECENT leaflet from Wild-Barfield Electric Furnaces, Ltd., describes the sealed quench slipper furnace which has been designed to make available controlled atmosphere conditions for the clean hardening of small parts such as miniature bearing cages and races, watch and instrument components. Provided the work is properly degreased before treatment, this furnace is said to produce a scale-free, clean finish.

Speed control of Electric Motors

'Variable' speed may involve two or three (or more) speed steps or infinitely variable (stepless) speed control. It is this latter type which is considered below. Of the many advantages of electric drives, the opportunity offered for infinitely variable speed control is outstanding. Unfortunately this advantage is not used as much as it might be to increase the speed of working, and to improve productivity and quality.

Principal Factors Affecting Choice of Drive

(a) First cost, (b) Efficiency, (c) Speed range, (d) Regulation, (e) Power-to-weight ratio, (f) Availability of supply, (g) Maintenance and reliability, (h) Change in power and torque over the speed range, (i) Simplicity of control gear, (j) Effect of variation in supply, (k) Power factor, (l) Characteristics of the load, (m) Operational environment, (n) Braking requirements.

This list is not meant to be all-embracing, for there well may be factors not mentioned which could prove conclusive in the choice of a drive.

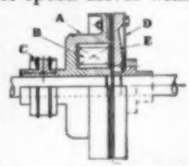
The following are some methods of obtaining infinitely variable speeds:

Alternating Current Motors

The vast majority of electric drives in use today employ A.C. motors. Although not quite so flexible as D.C. motors in the matter of speed control, there are available many types which give a large measure of speed variation.

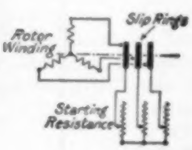
INDUCTION MOTORS. Although the squirrel-cage motor is essentially a constant-speed machine, it is much used for stepless variable speed drives with one of the following types:

(a) Eddy-current coupling,
(b) Ferro-magnetic particle coupling,
(c) Mechanical drives, e.g. belt drives and friction drives,
(d) Hydraulic variable speed drives.



A. Magnet body; B. Magnet coil; C. Collector gear; D. Spring plate; E. Armature.

SLIP-RING MOTOR. The slip-ring motor, which costs more than the squirrel-cage motor, can be varied in speed by means of the resistors in the rotor circuit used for starting. The amount of resistance in circuit can be varied in steps by means of different forms of control gear operated by hand, push-button or automatically controlled contactors.



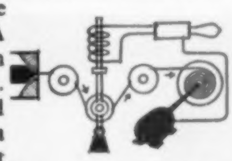
A.C. COMMUTATOR MOTORS. These are three-phase induction motors provided with additional windings which, through a commutator and brushes, permit speed adjustment in either direction below and above synchronous speed. The brush gear can be automatically controlled so as to vary the speed according to a known programme or cycle of operation such as in spinning frames. The Schrage and similar motors are refinements of this type.

Ward-Leonard System

In this system the armature of a D.C. motor is supplied at variable voltage from a separate generator. The generator may be driven by an A.C. or D.C. motor directly coupled to it and to an exciter which supplies the field windings of the generator and main motor. By means of a potentiometer resistance, with mid-point connected to one terminal of the generator field windings, the generator voltage may be varied from maximum to zero.

Electronic Motor Control

Motor speeds can be controlled accurately by electronic methods. Such drives can respond in any desired manner to variations in one or more variables and several drives can be interlocked so that their speeds are always in the same ratio. A typical application is on several separate conveyors. The system can be speeded up or slowed down from a 'master' controller, but for 'running in' purposes the speed of each drive can be individually regulated. Electronic speed control has been successfully applied where human control is not possible, e.g. in register control. In this example print must always be placed at exact positions on packaging material. The sketch shows electronic control of wire tension in drawing operations.



Direct Current Motors

While it is unlikely that a mains supply of D.C. will be available, the striking advantages of D.C. motors sometimes make it worth while installing a rectifier, e.g. a motor-generator set, a mercury-arc or a semi-conductor. The speed of D.C. motors is easily controlled by inserting a resistance in series with the motor. Although this can result in a certain amount of wasted electricity, the benefits derived will often heavily outweigh such losses.

For further information get in touch with your Electricity Board or write direct to the Electrical Development Association, 2 Savoy Hill, London, W.C.2. Telephone: TEMple Bar 9434.

Excellent reference books on electricity and productivity (8/6 each, or 9/- post free) are available —'Electric Motors and Controls' is an example.

E.D.A. also have available on free loan in the United Kingdom a series of films on the industrial uses of electricity. Ask for a catalogue.

CUT HERE

LABORATORY METHODS
MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC
INSTRUMENTS AND MATERIALS
MAY, 1961 Vol. LXIII, No. 379

Some Studies of the Performance of the K.1000 Cathode Ray Polarograph and Associated Anodic Conversion Unit

By J. O. Howden and G. F. Reynolds

Chemical Inspectorate, War Office, Royal Arsenal, Woolwich.

Experiments designed to obtain data relating to the performance of the Southern Instruments K.1000 cathode ray polarograph are described. Studies have been made with the instrument set for normal and for derivative working and with "cathodic" and "anodic" application of the potential sweep. Results obtained with the elements copper, lead, cadmium and zinc are presented and discussed. Conclusions are drawn regarding limits of detection, resolution of waves and ability to tolerate higher concentrations of a more noble species than that being determined. Certain aspects are discussed especially in relation to the use of ascorbic acid in solution and of anodic-derivative working.

THE basic principles of the linear-sweep single-sweep cathode ray polarograph were developed in detail by Randles in 1948[1,2] and a polarograph based upon these principles was described by Randles and Airey.[3] Subsequently an improved instrument was developed in the authors' department and full details were published in 1953.[4,5] This polarograph, under the type number K.1000, has been in commercial production by Southern Instruments, Ltd., for several years and is now in widespread use.

Apart from the high speed of operation the instrument has many advantages, including great sensitivity. Its associated derivative circuit also gives it very good power of resolution, and it has been shown that waves of half-wave potential only 38 mV. apart can be separately measured.[6] The details of a number of investigations made with either our own, or commercial instruments have been published in the literature.[7–11] These have illustrated the advantages of the instrument but, apart from two limited studies,[6,12] no detailed assessment of performance in relation to sensitivity and resolution has been reported.

The experiments described in this paper were therefore carried out to provide some data on which an overall assessment of performance could be based. At the same time the opportunity was taken to study the newly-designed Anodic Conversion Unit. This unit, which permits the potential of the dropping mercury electrode to be swept from negative to positive relative to the reference electrode, instead of in the conventional direction, would be expected to provide certain additional advantages, especially when used in conjunction with derivative working.[13]

EXPERIMENTAL

All experiments were carried out on a standard K.1000 cathode ray polarograph. The reference electrode was either a mercury pool or a silver wire anode. All peak potentials quoted are given in the European Sign Convention, on which the potential of the saturated calomel electrode (S.C.E.) is taken as $+$ 0·246 V. versus the normal hydrogen electrode (N.H.E.).

Copper, lead, cadmium and zinc were chosen for this work, since they were known to have good polarographic characteristics and because they provided a good coverage of the most commonly-employed potential range. They were examined singly and in various combinations, as described below. The effect of ascorbic acid on wave shape was also studied: this had been shown by Hetman[13] to have a beneficial effect, especially on "anodic" working.

Copper

Solutions of copper in 0·1 M potassium chloride were prepared and aliquots were withdrawn, deoxygenated by passage of very pure nitrogen for about 10 minutes, and polarographed. Determinations were made using both direct and derivative working and with "anodic" and "cathodic" application of the potential sweep. The range of copper concentration studied was 10 μg./ml. down to the lowest concentration which yielded a measurable wave. The experiments were then repeated using solutions which also contained 1% of ascorbic acid. A few solutions of copper in 0·1 M hydrochloric acid were also examined. The results obtained by direct polarography are given in Tables I and II, and typical waves are shown in Figs. 1, 2 and 3.

Table I shows that the lower limit of detection of copper under these conditions was relatively high. This was due to the interference of the steeply-sloping background in the region of zero volts applied potential. It is not peculiar to the copper reduction. In addition to making the higher sensitivity settings of the instrument unusuable, the slope also masked the foot of the reduction peak on cathodic working. Accurate measurement of the true peak height was therefore difficult, as shown by the

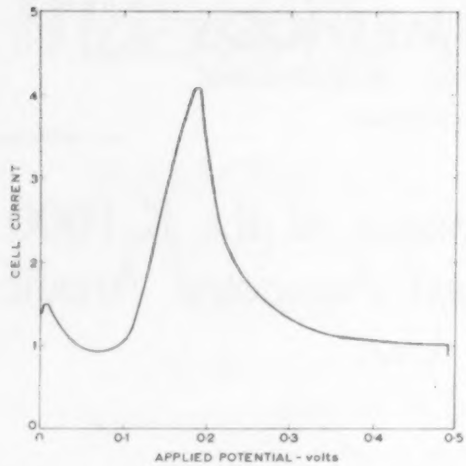


Fig. 1.—Wave obtained by direct polarography on solution containing 4 μg./ml. of copper in 0·1 M potassium chloride: sensitivity factor 0·6; start potential 0·0 V. (cathodic); mercury pool anode.

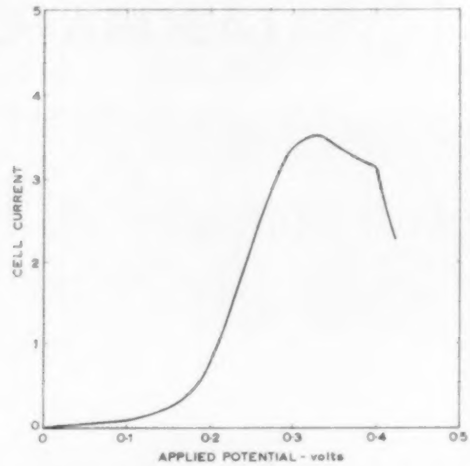


Fig. 2.—Wave obtained by direct polarography on solution containing 10 μg./ml. of copper in 0·1 M potassium chloride: sensitivity factor 0·4; start potential −0·45 V. (anodic); mercury pool anode.

poor linearity of the peak height-concentration relationship. An interesting feature was the sharp fall in peak current after the peak, as shown in Fig. 1. This indicated that replacement, by diffusion, of the ions removed during the initial stripping of the solution around the drop surface, was not sufficiently rapid for the limiting diffusion current to be attained.

Anodic working provided a much better step shape with a good foot to the peak. The sensitivity in terms of peak height for a given concentration, was generally higher, but the peak potential was much nearer zero volts. Therefore, although the step shape was good at higher copper concentrations (Fig. 2), the interference suffered from the background severely limited the sensitivity that could be employed, as shown in Fig. 3.

The addition of ascorbic acid to the solutions gave marked improvement. The amount of slope on the trace near zero volts was decreased and measurable steps were obtained down to 0·6 μg./ml. copper (*c.* 10^{-5} M) on cathodic working, although linearity failed at about 1 μg./ml. copper. The results on anodic working were again less satisfactory.

On a base electrolyte consisting of 0·1 M hydrochloric acid the cathodic results were very similar to those in potassium chloride. No wave on anodic working could, however, be distinguished.

On derivative working it was not possible to measure the copper peak, since it was almost entirely masked by the large peak at zero volts. No peak could be distinguished on anodic working.

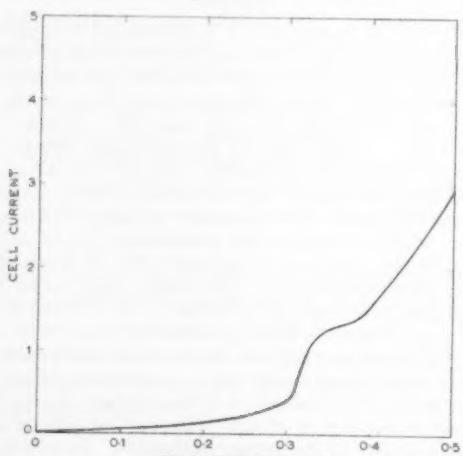


Fig. 3.—Wave obtained by direct polarography on solution containing 4 μg./ml. of copper in 0·1 M potassium chloride: sensitivity factor 0·6; start potential −0·45 V. (anodic); mercury pool anode.

Lead

Solutions of lead in 0·1 M potassium chloride were prepared and polarographed in the same way as those of

TABLE I.—COPPER IN 0·1 M POTASSIUM CHLORIDE
(*v.* mercury pool)

Copper Concentration (μg./ml.)	Cathodic (Start Potential = 0·0 V.)			Anodic (Start Potential = −0·45 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
10	−0·23	0·6	2·22	−0·03	0·4	3·45
8	−0·23	0·4	1·66	−0·03	0·25	3·9
6	−0·23	0·25	1·23	−0·03	0·25	2·8
4	−0·23	0·25	0·88			

TABLE II.—COPPER AND 1% ASCORBIC ACID IN 0·1 M POTASSIUM CHLORIDE
(*v.* mercury pool)

Copper Concentration (μg./ml.)	Cathodic (Start Potential = +0·1 V.)			Anodic (Start Potential = −0·4 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
10	−0·10	1·0	3·90	−0·04	0·6	2·61
8	−0·11	0·6	2·94	−0·03	0·6	2·22
6	−0·11	0·6	2·40	−0·02	0·4	1·86
4	−0·12	0·4	1·84	−0·03	4·0	1·40
2	−0·12	0·4	1·10	−0·03	0·25	0·86
1	−0·12	0·15	0·73			
0·8	−0·12	0·10	0·44			
0·6	−0·12	0·06	0·23			

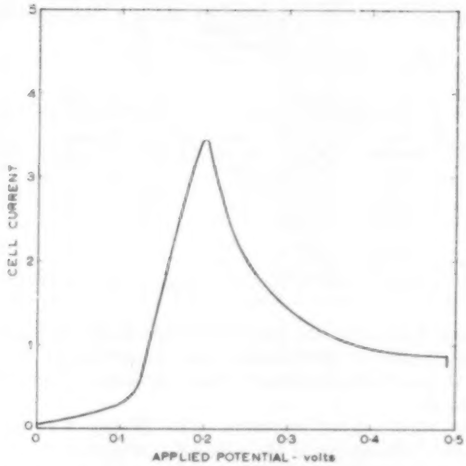


Fig. 4.—Wave obtained by direct polarography on solution containing 10 μg./ml. of lead in 0·1 M potassium chloride: sensitivity factor 0·4; start potential −0·3 V. (cathodic); mercury pool anode.

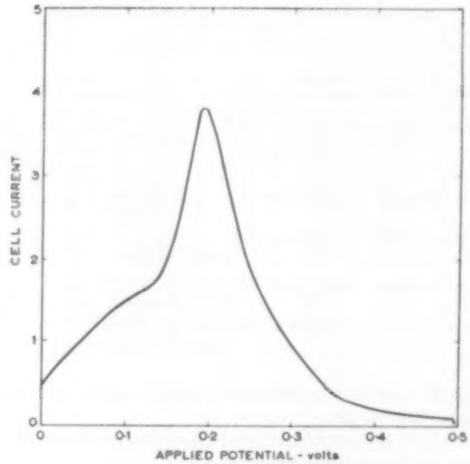


Fig. 5.—Wave obtained by direct polarography on solution containing 0·8 μg./ml. of lead in 0·1 M potassium chloride: sensitivity factor 0·025; start potential −0·3 V. (cathodic); mercury pool anode.

copper. The concentration range examined was from 10 μg./ml. down to the lowest concentration with which a measurable wave could be obtained. The experiments were also repeated in the presence of 1% ascorbic acid, and some determinations were made using 0·1 M hydrochloric acid as base electrolyte. The results are given in Tables III and IV, and typical waves are shown in Figs. 4, 5, 6 and 7.

The results in Table III show that on cathodic working lead gave a good linear relationship of peak height with concentration, and measurable waves were obtained down to 0·2 μg./ml. (*c.* 10^{-6} M). The wave shape was good in the higher concentrations studied (Fig. 4), but deteriorated as the lead content was decreased, as shown in Fig. 5: at the lowest concentration it was very poor. The wave shapes obtained when sweeping in the anodic direction were better than the cathodic waves at all concentrations, as illustrated by Figs. 6 and 7. The sensitivity was also slightly higher, but the peak-height-concentration relationship was less linear. Another factor evidently affected the peak height and caused enhancement at the lower concentrations, so that their value for determination of lead was dubious.

In the presence of ascorbic acid the lead waves were less well formed, and sharp fall in current occurred just before the lead reduction. This had little effect on sensitivity, however, and in fact a measurable cathodic wave was obtained with a lead concentration of 0·1 μg./ml. (see Table IV). This was only done with great difficulty, however, and would not be of practical use. The anodic results in this medium were fairly linear, but

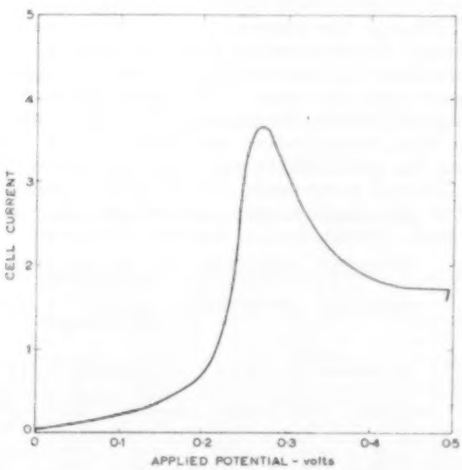


Fig. 6.—Wave obtained by direct polarography on solution containing 10 μg./ml. of lead in 0·1 M potassium chloride: sensitivity factor 0·4; start potential −0·7 V. (anodic); mercury pool anode.

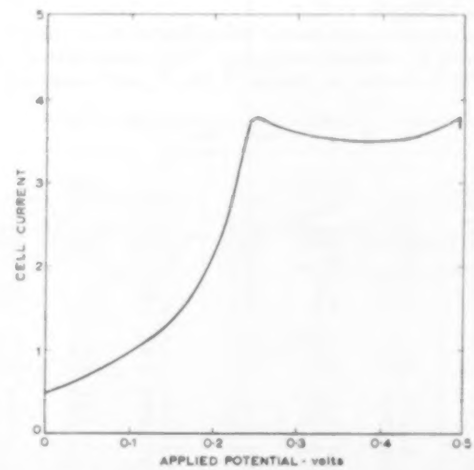


Fig. 7.—Wave obtained by direct polarography on solution containing 0·8 μg./ml. of lead in 0·1 M potassium chloride: sensitivity factor 0·06; start potential −0·7 V. (anodic); mercury pool anode.

TABLE III.—LEAD IN 0·1 M POTASSIUM CHLORIDE
(v. mercury pool)

Lead Concentration (μg./ml.)	Cathodic (Start Potential = −0·3 V.)			Anodic (Start Potential = −0·7 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
10	−0·50	0·4	1·40	−0·43	0·4	1·46
8	0·52	0·25	1·14	−0·44	0·25	1·18
6	−0·50	0·25	0·85	−0·43	0·25	1·04
4	−0·50	0·15	0·51	−0·43	0·25	0·76
2	−0·50	0·1	0·31	−0·45	0·15	0·53
1	−0·50	0·04	0·14	−0·43	0·1	0·32
0·8	−0·48	0·025	0·099	−0·47	0·06	0·26
0·6	−0·45	0·025	0·071	−0·42	0·06	0·29
0·4	−0·46	0·025	0·055	−0·42	0·06	0·26
0·2	−0·47	0·01	0·033			

the peak height-concentration graph again did not go through the origin.

In 0·1 M hydrochloric acid the results obtained were similar to those presented above.

No determinations were made on derivative working, and it was considered that this offered no advantages under the conditions employed.

Cadmium

Solutions of cadmium, in the same base electrolytes and with the same concentration ranges as those of copper and lead, were prepared and polarographed. The polarographic conditions were the same as previously employed, but only direct polarography was carried out. The results are presented in Tables V and VI, and typical sets of cathodic and anodic waves are shown in Figs. 8 and 9.

Table V shows that cadmium gave very good results. The peak height relationship was excellent in the range 10–1 μg./ml. and good even down to 0·02 μg./ml. This concentration, which is equivalent to $1{\cdot}8 \times 10^{-7}$ M, was the limit of detection obtained. It might, however, have been improved by the use of a silver wire anode instead of the mercury pool. The waves at the higher concentrations were of good shape, but deteriorated progressively at lower concentrations. This is illustrated by the waves in Fig. 8.

The anodic waves were of rather better shape than those obtained by cathodic sweeping. They deteriorated more rapidly, however, as shown in Fig. 9, and could not be

TABLE V.—CADMIUM IN 0·1 M POTASSIUM CHLORIDE
(v. mercury pool)

Cadmium Concentration (μg./ml.)	Cathodic (Start Potential = −0·45 V.)			Anodic (Start Potential = −0·9 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
10	−0·68	0·6	2·70	−0·66	1·0	3·30
8	−0·68	0·6	2·19	−0·66	0·6	2·76
6	−0·67	0·4	1·64	−0·65	0·6	2·04
4	−0·67	0·25	1·09	−0·65	0·4	1·40
2	−0·67	0·15	0·54	−0·65	0·15	0·735
1	−0·67	0·06	0·26	−0·65	0·10	0·380
0·8	−0·67	0·04	0·20	−0·66	0·06	0·300
0·6	−0·67	0·04	0·14	−0·65	0·06	0·249
0·4	−0·66	0·025	0·095	−0·64	0·04	0·182
0·2	−0·66	0·015	0·045	−0·64	0·025	0·105
0·1	−0·67	0·006	0·02	−0·64	0·025	0·050
0·08	−0·66	0·006	0·019			
0·06	−0·66	0·004	0·015			
0·04	−0·67	0·004	0·0104			
0·02	−0·67	0·004	0·006			

TABLE IV.—LEAD AND 1% ASCORBIC ACID IN 0·1 M POTASSIUM CHLORIDE
(v. mercury pool)

Lead Concentration (μg./ml.)	Cathodic (Start Potential = −0·2 V.)			Anodic (Start Potential = −0·6 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
1	−0·41	0·04	0·14	−0·33	0·06	0·234
0·8	−0·41	0·025	0·11	−0·34	0·06	0·210
0·6	−0·40	0·025	0·086	−0·34	0·04	0·186
0·4	−0·40	0·015	0·057	−0·34	0·04	0·144
0·2	−0·40	0·010	0·031			
0·1	−0·41	0·004	0·013			

measured at cadmium concentrations below 0·1 μg./ml. A high degree of reversibility was suggested by the fact that the cathodic and anodic peak potentials were almost identical.

The presence of ascorbic acid (Table VI) greatly improved the shape of the cathodic cadmium waves. In particular, the sharp fall in current just before the start of the reduction was almost entirely eliminated, providing a much more satisfactory base for measurement. Surprisingly, however, the increase in accuracy was not significant and the limit of detection previously achieved was not improved. The use of 0·1 M hydrochloric acid as base electrolyte gave no advantages.

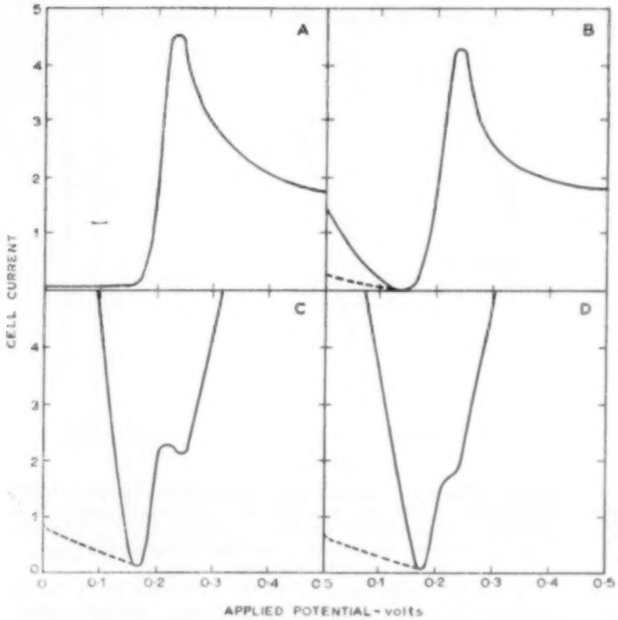
Zinc

Solutions of zinc in 0·1 M potassium chloride and in 0·1 M hydrochloric acid were prepared and polarographed, using direct polarography exactly as for the elements previously studied. The results are given in Tables VII and VIII, and typical waves for low zinc concentrations are shown in Figs. 10, 11 and 12.

The results presented in Table VII show that on cathodic working peak height was proportional to zinc concentration down to 0·2 μg./ml. Below this level deviation from linearity occurred and became increasingly obvious. The wave was, however, measurable down to 0·008 μg./ml. (Fig. 11). This concentration, which is equivalent to $1{\cdot}2 \times 10^{-7}$ M, was considered to represent the lowest concentration capable of giving a measurable wave, although the instrument was not at maximum sensitivity. Synchronisation was difficult at the lowest concentrations and some skill was necessary to maintain the wave upon the screen. The peak height was increasingly affected by the reduction of the base electrolyte as the zinc concentration was reduced. On anodic working the peak heights were somewhat greater than those obtained cathodically, but linearity began to fail at about the same concentration and the slope on the trace made synchronisation difficult.

TABLE VI.—CADMIUM AND 1% ASCORBIC ACID IN 0·1 M POTASSIUM CHLORIDE
(v. mercury pool)

Cadmium Concentration (μg./ml.)	Cathodic (Start Potential = −0·4 V.)			Anodic (Start Potential = −0·8 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (A.)	Peak Potential (V.)	Sensitivity Scale Factor	Peka Height (μA.)
1	−0·56	0·06	0·273	−0·52	0·10	0·345
0·8	−0·56	0·06	0·219	−0·53	0·06	0·279
0·6	−0·63	0·04	0·188	−0·55	0·06	0·228
0·4	−0·64	0·04	0·152	−0·55	0·04	0·174
0·2	−0·60	0·015	0·072	−0·51	0·025	0·104
0·1	−0·65	0·010	0·032			



A. 10 μg./ml. of cadmium; sensitivity factor 0·6.

B. 1 μg./ml. of cadmium; sensitivity factor 0·006.

C. 0·04 μg./ml. of cadmium; sensitivity factor 0·004.

D. 0·02 μg./ml. of cadmium; sensitivity factor 0·004.

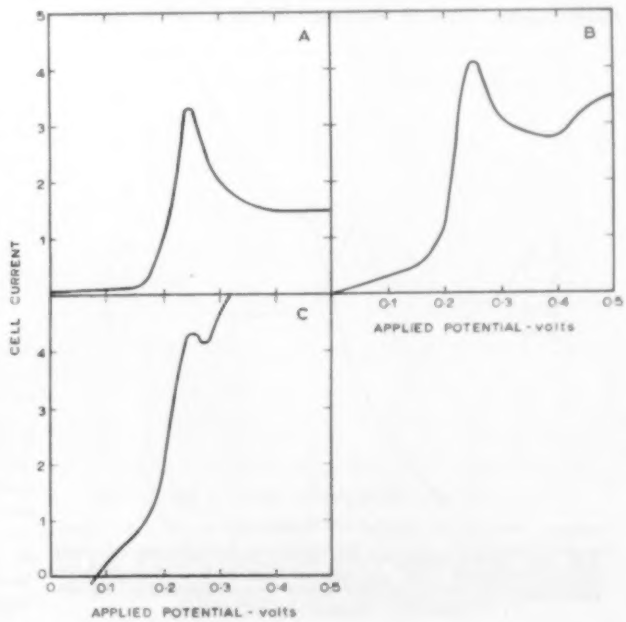
Fig. 8.—Waves obtained by direct polarography on solutions containing cadmium in 0·1 M potassium chloride: start potential −0·5 V (cathodic); mercury pool anode. Broken line indicates the effect of ascorbic acid on the base of the wave.

In the presence of ascorbic acid linearity was again good down to 0·2 μg./ml. of zinc, but little improvement in wave shape was noted. Below this level merging of the peak with the background made measurement impossible.

Polarography of zinc in 0·1 M hydrochloric acid was found to be unsatisfactory. As was expected, the steep rise of the hydrogen discharge made synchronisation difficult to achieve at sensitivity scale factors less than 0·1 of cathodic working. On anodic working this was less serious, but no improvement in the lower limit of detection was achieved. When a base electrolyte of 0·01 M hydrochloric acid was tried the waves obtained were badly formed.

Mixtures of Ion Species

In order to assess the ability of the K 1000 cathode ray polarograph to tolerate higher concentrations of an ion species more noble than that being determined, three series of solutions were prepared, each containing two of the metals already studied. As before, the base electrolytes employed were 0·1 M potassium chloride and 0·1 M potassium chloride containing 1% ascorbic acid. Polarography was carried out as already described in the study



A. 10 μg./ml. of cadmium; sensitivity factor 1·0.

B. 1 μg./ml. of cadmium; sensitivity factor 0·1.

C. 0·2 μg./ml. of cadmium; sensitivity factor 0·025.

Fig. 9.—Waves obtained by direct polarography on solution containing cadmium in 0·1 M potassium chloride: start potential −0·9 V. (anodic); mercury pool anode.

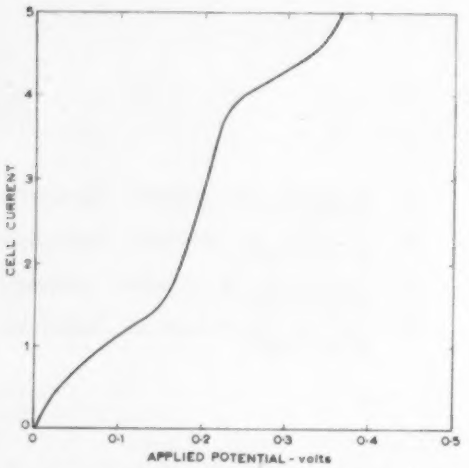


Fig. 10.—Wave obtained by direct polarography on solution containing 0·01 μg./ml. of zinc in 0·1 M potassium chloride: sensitivity factor 0·01; start potential −0·85 V. (cathodic); mercury pool anode.

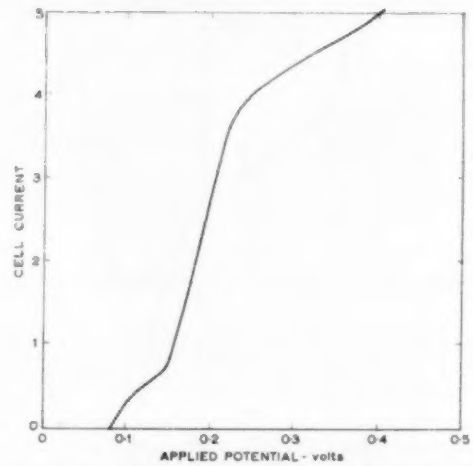


Fig 11.—Wave obtained by direct polarography on solution containing 0·008 μg./ml. of zinc in 0·1 M potassium chloride: sensitivity factor 0·006; start potential −0·85 V. (cathodic); mercury pool anode.

of the single species. The metals were arranged in successive pairs so that lead was determined in the presence of excess copper, cadmium in the presence of excess lead and zinc in the presence of excess cadmium. Direct and derivative polarography, with both cathodic and anodic application of the potential sweep, were employed in these experiments.

Lead in the Presence of Excess Copper

Direct polarography of lead in the presence of excess copper, with cathodic application of potential, showed that concentrations as low as 0·2 μg./ml. of lead could be determined in the presence of 10 μg./ml. of copper. A higher copper concentration could not be tolerated, however, owing to the limitation of the Y shift of the instrument. Anodic working offered no advantages.

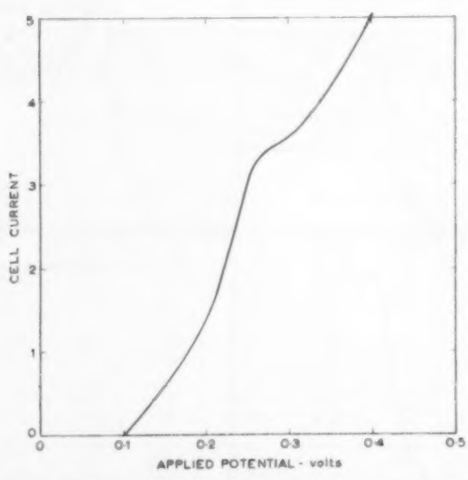


Fig. 12.—Wave obtained by direct polarography on solution containing 0·01 μg./ml. of zinc in 0·1 M potassium chloride: sensitivity factor 0·006; start potential −1·3 V. (anodic); mercury pool anode.

Derivative polarography of the solutions gave rather unsteady waves on cathodic working. Better results were obtained when anodic sweeping of the potential was employed, and a further increase in stability and improvement in wave shape occurred when ascorbic acid was present. In these experiments both the mercury pool and the silver-silver chloride wire anode were employed.

TABLE VII.—ZINC IN 0·1 M POTASSIUM CHLORIDE
(*v.* mercury pool)

Zinc Concentration (μg./ml.)	Cathodic (Start Potential = −0·85 V)			Anodic (Start Potential = −1·3 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
10	−1·07	1·0	4·30	−1·05	1·5	5·48
8	−1·07	1·0	3·40	−1·04	1·0	4·30
6	−1·07	0·6	2·55	−1·04	1·0	3·20
4	−1·07	0·4	1·76	−1·05	0·6	2·22
2	−1·07	0·25	0·90	−1·05	0·25	1·16
1	−1·07	0·1	0·43	−1·06	0·15	0·555
0·8	−1·07	0·1	0·35	−1·05	0·10	0·410
0·6	−1·07	0·06	0·285	−1·05	0·10	0·365
0·4	−1·07	0·06	1·210	−1·05	0·06	0·276
0·2	−1·07	0·04	0·128	−1·05	0·04	0·156
0·1	−1·07	0·04	0·128	−1·05	0·04	0·172
0·08	−1·06	0·025	0·111	−1·05	0·04	0·146
0·06	−1·05	0·025	0·094	−1·04	0·04	0·136
0·04	−1·05	0·025	0·075	−1·04	0·025	0·098
0·02	−1·1	0·01	0·050	−1·02	0·015	0·054
0·01	−1·1	0·01	0·030			
0·008	−1·1	0·01	0·025			

TABLE VIII.—ZINC AND 1% ASCORBIC ACID IN 0·1 M POTASSIUM CHLORIDE
(*v.* mercury pool)

Zinc Concentration (μg./ml.)	Cathodic (Start Potential = −0·8 V.)			Anodic (Start Potential = −1·2 V.)		
	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)	Peak Potential (V.)	Sensitivity Scale Factor	Peak Height (μA.)
1	−1·04	0·15	0·57	−0·94	0·15	0·615
0·8	−1·04	0·10	0·445	−0·94	0·15	0·510
0·6	−1·04	0·10	0·37	−0·94	0·10	0·410
0·4	−1·04	0·06	0·258	−0·94	0·06	0·294
0·2	−1·04	0·04	0·142	−0·94	0·04	0·180
0·1				−0·94	0·04	0·132
0·08				−0·94	0·025	0·095

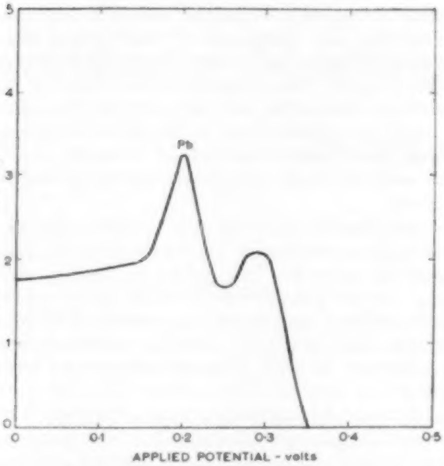


Fig. 13.—Wave obtained by anodic-derivative polarography on solution containing 2 μg./ml. of lead in presence of 200 μg./ml. of copper in 0·1 M potassium chloride: sensitivity factor 0·01; start potential −0·7 V. (anodic); silver-silver chloride wire anode.

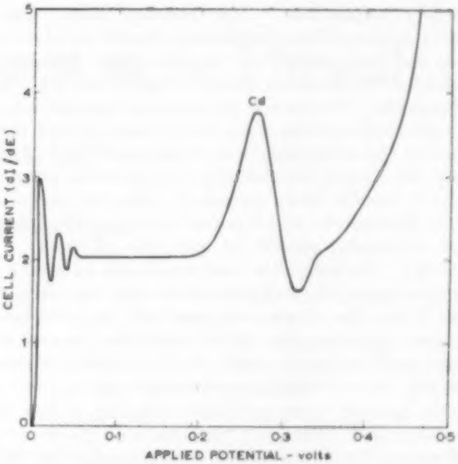


Fig. 14.—Wave obtained by anodic-derivative polarography on solution containing 0·6 μg./ml. of cadmium in presence of 1,000 μg./ml. of lead in 0·1 M potassium chloride: sensitivity factor 0·015; start potential −0·9 V. silver-silver chloride wire anode.

The latter gave much better results on high instrumental sensitivities.

Under the optimum conditions a copper : lead ratio of 100 : 1 could be polarographed and a copper concentration of 200 μg./ml. could be tolerated. At higher copper concentration a precipitate appeared. The nature of this precipitate was not investigated, but it seemed probable that it was a copper complex with ascorbic acid.

A typical anodic-derivative wave is shown in Fig. 13.

Cadmium in the Presence of Excess Lead

Direct polarography of these two species showed that, on anodic working, 0·2 mg./ml. of cadmium could be determined in the presence of 10 μg./ml. of lead. Higher lead concentrations could not be tolerated. The presence of ascorbic acid did not improve this ratio.

On derivative working the best results were again obtained with anodic sweeping and with a silver-silver chloride wire reference electrode. Stable cadmium peaks were obtained in the presence of 1 μg./ml. of lead, and a lead : cadmium ratio of 1500 : 1 could be tolerated without difficulty. In fact, it appeared more likely that an increase in this ratio would be limited by insolubility of lead chloride than by polarographic interference.

A typical anodic-derivative wave is shown in Fig. 14.

Zinc in the Presence of Excess Cadmium

Zinc concentrations down to 0·1 μg./ml. were determined by direct polarography in the presence of 10 μg./ml. of cadmium. Higher cadmium concentrations gave too large a standing wave.

The use of anodic-derivative polarography was again shown to give the best results. The additional advantages of ascorbic acid and the use of a silver-silver chloride anode were small in this case, as the separation of the waves was much greater than those already considered. Very large excesses of cadmium could be tolerated and 1 μg./ml. of zinc was determined without difficulty in the presence of 2 mg./ml. of cadmium. Higher ratios of these elements were not studied, but it appeared that, on purely polarographic grounds, the amount of cadmium that could be present was virtually unlimited.

A typical anodic-derivative wave is shown in Fig. 15.

DISCUSSION

The sensitivity scale of the K 1000 cathode ray polarograph is graduated in "factors" by which the vertical scale on the cathode ray tube face must be multiplied to obtain current values directly in microamps. The maximum sensitivity is represented by the factor 0·004 and, as shown in Tables IV and V, the instrument was actually used at this limit during the experiments with lead and cadmium. The use of the highest sensitivities of the cathode ray polarograph is never easy, and is

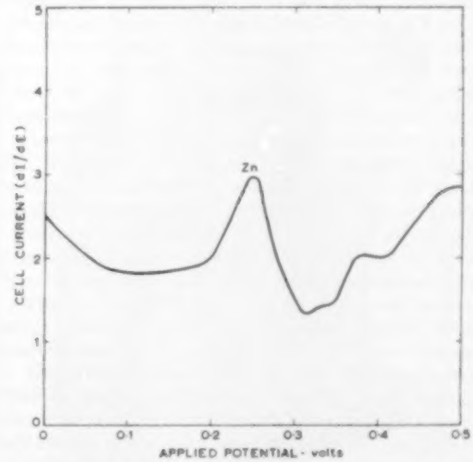


Fig. 15.—Wave obtained by anodic-derivative polarography on solution containing 1 μg./ml. of zinc in presence of 800 μg./ml. of cadmium in 0·1 M potassium chloride: sensitivity factor 0·015; start potential −1·3 V. (anodic); silver-silver chloride wire anode.

frequently impossible. The present cases, however, probably represent near optimum conditions of reducible species and base electrolyte, and no great difficulty was experienced in obtaining waves of sufficient stability for measurement. No special precautions against vibration of the electrode system were taken, except that the best position in the laboratory was chosen and care was taken to keep the size of the mercury pool as small as possible. The best results were obtained with the silver-silver chloride wire anode, and it is recommended that this, or a similar electrode, should be used for all work of high sensitivity. Considerable care was taken in earthing the polarograph and electrode stand so that the background "hum" on the trace was reduced to a minimum. Previous experience has shown that the lack of a very efficient and isolated earth can seriously reduce the sensitivity factor which can be employed.

Little has yet been published relating to the anodic conversion unit. This unit provides a means of reversing the direction of the potential sweep applied to the electrodes, so that the potential of the dropping mercury electrode is driven in a positive direction with respect to the reference electrode. If, therefore, the start potential of the instrument is set at a value more negative than that of the peak potential of the species under examination, the electrode reaction will be in progress during the "rest" period of the polarograph and will increase in magnitude as the drop grows. When the sweep commences the dropping mercury electrode will be driven to a more positive potential and the reaction will first cease and then be reversed in direction at a potential and with an efficiency depending upon the nature of the species and also upon the reversibility of the process. Both the applied voltage and the resulting cell current are thus reversed in direction compared with those normally fed to the X and Y deflector plates of the cathode ray tube. The anodic unit, however, provides reversals in each of these circuits, so that the polarogram obtained is apparently the same as for "cathodic" working.

The majority of the work so far carried out with the anodic conversion unit has been done by Hetman[13] and most of it is not yet published. His work has shown that the use of this unit can give rise to better wave shape and greater sensitivity than those obtained on cathodic working, but that the reverse may also be true. At present the possibilities of the unit in any particular case are best ascertained by experiment. Our results tend to support those of Hetman but, in general, it appears that anodic sweeping does not offer marked advantages in many cases when normal polarography is employed.

The major advantage of the anodic conversion unit appears to lie in its use with derivative polarography. This is particularly true when a species has to be determined in the presence of a much larger quantity of a material which reduces at a more positive potential. Application of the potential sweep in the anodic direction allows the peak due to the minor constituent to be examined first, before that of the major constituent appears and the usual difficulties are therefore avoided. This has, of course, been done at a much earlier date by reversing the direction of the potential sweep on a conventional derivative polarograph, but the value of the method has not hitherto been great, due to the loss in sensitivity associated with derivative working. Used in conjunction with the cathode ray polarograph, however, the great sensitivity available makes it an important technique for the treatment of problems of this type. Our results, in agreement with those earlier obtained by Hetman, support this conclusion, and indicate that the sensitivities obtainable and the ratio of the ion species that may be tolerated are a considerable advance on anything previously obtained by cathode ray polarography and may approach those of other special types of instrument.

The function of ascorbic acid in the solution seems almost entirely confined to the removal of the last traces of dissolved oxygen. This leads, as already shown by Hetman, to the production of much better curves with flatter base lines, making measurement of wave heights easier and more accurate. The use of this reagent for deoxygenation in acid solution appears to have been neglected.

The results obtained with copper (Tables I and II) were less satisfactory than those with the other elements studied. This is a feature commonly experienced with cathode ray polarography at potentials near zero volts. It is not peculiar to copper. An important factor is the marked improvement obtained in the presence of ascorbic acid.

The linearity of the step height concentration relationship obtained with the lower cadmium concentrations was surprising, especially in view of the steeply-sloping bases of the waves. The considerable improvement effected by the addition of ascorbic acid is a good example of the value of this reagent (Fig. 8). It appears from this that the slope on the base was due to traces of dissolved oxygen, in spite of the considerable precautions taken to ensure purity of the deoxygenating gas and to provide adequate sealing against entry of air. Similar improvements should be obtained with other species, and further investigation is merited.

The steep slope on the trace, upon which the zinc was superimposed, is a serious limitation on the sensitivity and accuracy obtainable in this region of applied potential. Improvement, especially in case of synchronisation and measurement, would probably be achieved if the instrument were fitted with a circuit analogous to the "countercurrent" used in conventional polarography.

In conclusion, it should be emphasised that this assessment is not intended to be exhaustive, but is regarded by us as an initial survey upon which further work will be based in the future. In particular, it is necessary to bear in mind that the conditions should be chosen to allow the optimum performance of the instrument in question to be achieved, and that comparative assessment of several instruments using a single set of solutions may be misleading. Assessments of other polarographs, under suitably chosen conditions, will be published later.

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Exhibits of Metallurgical Interest at the Physical Society Exhibition

(*Continued from page 210 of the April issue*)

The Microspin

ONE of the exhibits on the Hilger & Watts stand was a prototype electron spin resonance spectrometer under development by the company in co-operation with Microwave Instruments, Ltd., using microwave frequencies in the Q-band and the X-band.

Samples are placed in a resonant cavity situated in a magnetic field which is slowly swept through the resonance value. The analytical samples are characterised by the existence of impaired electron spins, as in free radicals and paramagnetic solids, and the resonance condition occurs when the electronic splitting in a quasi-static magnetic field corresponds to a quantum of radiation at the particular microwave frequency: energy is then absorbed by the sample. The cavity forms part of a microwave bridge circuit which is unbalanced when the sample absorbs energy, giving a proportional output to the measuring circuits.

To achieve maximum sensitivity, an alternating magnetic field at a high frequency—in this case 100 kc./s.—is superimposed on the steady field at the sample. The modulated bridge output is fed to a low-noise narrow-band amplifier and a phase-sensitive detector, and is then displayed on a meter, a cathode-ray oscillograph or a pen recorder.

A Pound frequency stabiliser using an intermediate frequency of 45 Mc./s. is included to maintain the klystron frequency at the resonance frequency of the cavity over a range of temperatures of at least $\pm 100°$ C. The resolution of the instrument is achieved by using an electromagnet giving a field of high homogeneity (about 1 part in 10^5 over the sample volume) supplied by a suitable current stabiliser. The magnet gap is great enough to allow the cavity to be immersed in a suitable cryostat for low-temperature working.

High Vacuum Coating Plant

The vacuum coating plant exhibited on the stand of Edwards High Vacuum, Ltd., included the Speedivac 6E2, a redesigned miniature unit incorporating most of the refinements found in large scale apparatus, and the Speedivac 19E1, specially designed for the preparation of films of magnetic materials and experimental or production work on transistors or other solid state devices which, because of contamination hazards, must be vacuum processed at pressures lower than those obtainable in a conventional industrial coating plant. The 19 in. diameter stainless steel work chamber seals to the baseplate by an indium wire gasket. Four evaporation sources are available together with discharge cleaning and radiant heating facilities. A liquid-nitrogen-cooled condenser mounted above the pumping aperture in the baseplate, and just within the work chamber, acts as a very high speed pump for the removal of condensable vapours. The work chamber is evacuated, via a stainless steel baffle valve, by a Speedivac F903 self-purifying diffusion pump and a 1SC450B pump.

The Hilger Microspin electron spin resonance spectrometer.

The Speedivac 19E1 vacuum coating unit.

The foregoing coating plants are in production, and the other unit shown—model 12E8—has reached the "planned for production" stage. This plant can be used for the production of thin metal films at low pressure; in particular for the experimental production of transistors, magnetic, or super-conducting films. The system is made of stainless steel components throughout, and the work chamber measures 12 in. diameter $\times$ 15 in. high. All demountable seals are made with aluminium wire gaskets, and the lead-in electrodes are of gas to metal type. The system is pumped, via a 2 in. vapour trap and a water-cooled baffle, by an F403 self-purifying oil diffusion pump, and when the ultimate pressure of the diffusion pump system is reached, a getter is used to decrease the pressure still further. The system above the water-cooled baffle is bakeable to 450° C. A pressure of 10^{-7} torr is achieved after 3 hours pumping, and 10^{-9} torr after $3\frac{1}{2}$ hours baking to 320° C. and 7 hours pumping. Less than 10^{-9} torr pressure is obtained after 7 hours pumping and firing the getter ($3\frac{1}{2}$ hours baking to 320° C.).

Interference Objective

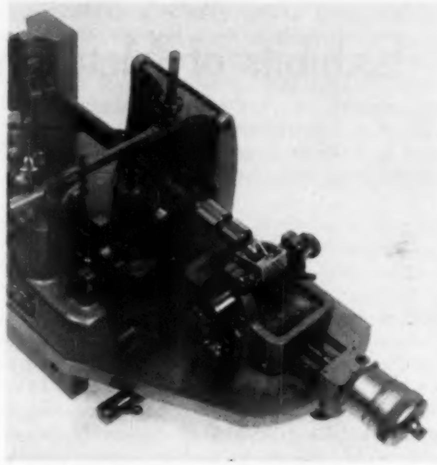
For the examination of specimens by reflected light at approximately $\times 100$ magnification, W. Watson & Sons, Ltd., showed an objective which produces an interference fringe pattern on the specimen corresponding to variations in height of the surface. A special beam-splitting prism mounted below the front lens of the objective divides light from the source so that the specimen and a reference mirror can be viewed simultaneously. The reference mirror can be adjusted by a fine screw to make the path lengths similar, and can be tilted by means of two other screws for parallelism. The prism, condensing lenses and reference mirror with adjusting screws, are all fitted to the objective in one unit which will fit on to almost any microscope having a standard R.M.S. objective thread.

The objective has a focal length of 16 mm. and a numerical aperture of 0·2, giving a lateral resolution of about 1·5 micron. By inspecting the pattern of interference fringes, surface figures and irregularities smaller than about one-tenth of a wavelength (0·06 micron) deep can be resolved. The diameter of the field of view is 1·3 mm.

Any highly polished reflecting surface can be examined, and measurements of scratch depth, pit depth, layer thickness or small bevel angles can be made. In the semi-conductor field it has been proved useful for measuring diffused layer thickness by bevelled polishing and staining. The Lan-Sabattier photographic technique can be used to produce a photograph showing fine lines representing contours of equal intensity on the original fringe pattern.

Ultra-microtome

The examination of thin metal foils by transmission electron microscopy is an increasingly important metallurgical technique. In order to see the detailed sub-microscopic structure of the foils they must be very thin, and one means of producing such thin foils from solid specimens is by means of a microtome which cuts slices from the surface. Originally developed in the Engineering Laboratory of Cambridge University, by Mr. A. F. Huxley, F.R.S., the ultra-microtome shown by Cambridge Instrument Co., Ltd., was originally intended for preparing thin sections of biological tissue, but, fitted with a diamond knife, it has proved successful for metallographic work. All the mechanisms of the instrument are mechanical in operation, and the force for the cutting stroke is provided by gravity. The rate of fall of the specimen past the knife can be adjusted to give the best speed for any type of specimen from soft biological tissues to hard materials like metals. Sections of metals down to 100 mμ (1,000 Å) thickness can be cut successfully.



The Huxley ultra-microtome fitted with a diamond knife.

High Temperature Thermocouples

A range of high temperature thermocouples incorporating non-metallic materials, for service at temperatures in the range 1,600°–2,000° C., or higher, when conventional metallic couples fail, was featured on the Morgan Crucible stand. Some of the materials, being semi-conductors, provide a very high voltage output, compared with metals. For example, a silicon-carbide/graphite couple can be made to give 0·2 V. at 1,000° C.

Modification of the properties of silicon carbide and graphite, by controlled adjustment of composition, allows couples to be made from two types of silicon carbide or two types of graphite. Alternatively, any of these materials can be run against a refractory metal. Thermocouples of graphite against tungsten, rhenium or rhenium-tungsten are specially interesting when temperature measurement is required under strongly reducing conditions, e.g. in contact with graphite or in carbonaceous atmospheres.

Associated Electrical Industries, Ltd., is to receive an order from the Central Electricity Generating Board Midlands Project Group for two 400 MVA generator transformers for connection to the supergrid at the Drakelow "C" Power Station near Burton-on-Trent. These generator transformers, value over £400,000, are the largest so far ordered by C.E.G.B. and they will connect two 375 MW super critical turbine-generators to the grid system. AEI is manufacturing one of these 375 MW turbine generators.

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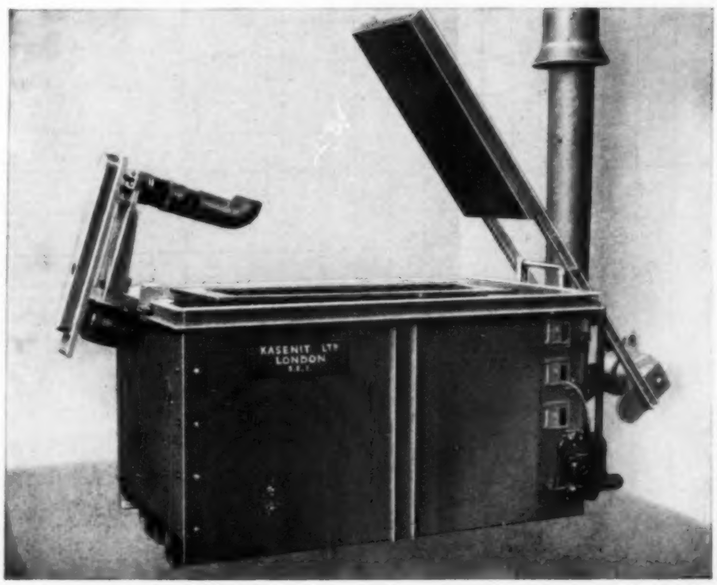


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